

UNCLASSIFIED

AD NUMBER

AD912715

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to DoD only; Test and Evaluation; 01 MAR 1973. Other requests shall be referred to Office of Naval Research, Arlington, VA 22203.

AUTHORITY

ONR ltr 15 Mar 1979

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Stanford Research Institute Menlo Park, California 94025		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP	
3. REPORT TITLE GUIDE TO FIRE SUPPORT MIX EVALUATION TECHNIQUES Volume 1: THE GUIDE AND APPENDICES A AND B			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report			
5. AUTHOR(S) (First name, middle initial, last name) Robert J McNicholas, Fredrick L. Crane			
6. REPORT DATE March 1973		7a. TOTAL NO. OF PAGES 280	7b. NO. OF REFS 32
8a. CONTRACT OR GRANT NO. N00014-71-C-0417		9a. ORIGINATOR'S REPORT NUMBER(S)	
b. PROJECT NO. RF 018-96-01			
c. NR 274-008-44		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.			
10. DISTRIBUTION STATEMENT Distribution limited to DoD agencies only: Test and Evaluation 19 July 1973. Other requests for this document must be referred to the Office of Naval Research (Code 462).			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Naval Analysis Programs (Code 462) Office of Naval Research Arlington, Virginia 22217	
13. ABSTRACT This document in two volumes is a guide to fire support mix evaluation techniques. The Guide results from research conducted with the overall objective of identifying a comprehensive methodology for evaluating fire support system mixes. Volume 1 (unclassified) contains the Guide proper in four parts. Part I contains the analysis of the fire support function and process including definitions, descriptions, future trends, key elements, parameters, and interrelationships with other combat functional areas. Part II describes existing fire support methodologies, identifies their strong and weak points, and suggests alternative approaches. Methodologies are assessed from both an overall and a key element viewpoint. Part III synthesizes the salient methodological issues. Part IV contains suggested procedures for use of an analyst in the conduct and management of a fire support mix evaluation study, relationship of existing and alternative techniques to key elements, strengths and weaknesses of existing methodologies, how existing studies answer fire support questions, criteria for evaluating studies, and pitfalls to be avoided. Also in Volume I are Appendices A and B, which provide a listing of system parameters and a bibliography. Volume II is classified and consists of Appendix C, which provides summary analyses of 14 selected fire support studies used as the basic data base.			

DD FORM 1473 (PAGE 1)

S/N 0101-807-6801

iii

UNCLASSIFIED

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fire Support Mix Evaluation						
Fire Support Techniques						
Fire Support Methodology						
Fire Support Systems						
Fire Support Guide						
Fire Support Analysis						
Supporting Arms						
Fire Support Parameters						
Fire Mission Generation						
Fire Mission Allocation						
Fire Support System Effectiveness						
Cost Analysis						
Fire Support System Mix Preference Selection						
Fire Support Models						

92012
TECHNICAL REPORT SECTION
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93940

LIBRARY
TECHNICAL REPORT SECTION
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93940

*Naval Warfare Research Center
Final Report*

1 March 1973

GUIDE TO FIRE SUPPORT MIX EVALUATION TECHNIQUES

Volume I: The Guide and Appendices A and B

By: R. J. McNICHOLAS F. L. CRANE

Prepared for:

NAVAL ANALYSIS PROGRAMS (CODE 462)
OFFICE OF NAVAL RESEARCH
ARLINGTON, VIRGINIA 22217

CONTRACT N00014-71-C-0417
Task No. NR 274-008-44

Reproduction in whole or in part is permitted for any purpose of the United States Government.

Distribution limited to DOD agencies only: Test and Evaluation — 19 July 1973. Other requests for this document must be referred to the Office of Naval Research (Code 462).



STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 • U.S.A.

AN (1) AD- 912 715
 FG (2) 150600
 CI (3) (U)
 CA (5) STANFORD RESEARCH INST MENLO PARK CA NAVAL WARFARE
 RESEARCH CENTER
 TI (6) Guide to Fire Support Mix Evaluation Techniques. Volume
 I. The Guide and Appendices A and B.
 DN (9) Final rept.,
 AU (10) McNicholas, Robert J.
 AU (10) Crane, Fredrick L.
 RD (11) Mar 1973
 PG (12) 255
 CT (15) N00014-71-C-0417
 PJ (16) RF018-96
 PJ (16) SRI-1319-10
 TN (17) RF018-96-01
 RC (20) Unclassified report
 DE (23) , (*CLOSE SUPPORT, TACTICAL WEAPONS), MARINE CORPS,
 AMPHIBIOUS OPERATIONS, MISSION PROFILES, NAVAL GUNNERY,
 ARTILLERY FIRE, TACTICAL AIR SUPPORT, MOBILITY, COMBAT
 SURVEILLANCE, TARGET ACQUISITION, SURFACE TARGETS,
 COMMAND AND CONTROL SYSTEMS, MILITARY INTELLIGENCE,
 ARMORED VEHICLES, MANAGEMENT PLANNING AND CONTROL,
 THREAT EVALUATION, MILITARY TACTICS, INFANTRY,
 LOGISTICS, COSTS, EFFECTIVENESS, WAR GAMES, COMPUTER
 PROGRAMMING.
 DC (24) (U)
 AB (27) This document is a guide to fire support mix evaluation
 techniques. The Guide results from research conducted
 with the overall objective of identifying a
 comprehensive methodology for evaluating fire support
 system mixes. The Guide proper is in four parts. Part I
 contains the analysis of the fire support function and
 process including definitions, descriptions, future
 trends, key elements, parameters, and
 interrelationships with other combat functional areas.
 Part II describes existing fire support methodologies,
 identifies their strong and weak points, and suggests
 alternative approaches. Methodologies are assessed from
 both an overall and a key element viewpoint. Part III
 Synthesizes the salient methodological issues. Part IV
 contains suggested procedures for use of an analyst in
 the conduct and management of a fire support mix
 evaluation study, relationship of existing and
 alternative techniques to key elements, strengths and
 weaknesses of existing methodologies, how existing
 studies answer fire support questions, criteria for
 evaluating studies, and pitfalls to be avoided.

AC (28) (U)

DL (33) 01



STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

Naval Warfare Research Center
Final Report

1 March 1973

GUIDE TO FIRE SUPPORT MIX EVALUATION TECHNIQUES

Volume I: The Guide and Appendices A and B

By: R. J. McNICHOLAS F. L. CRANE

Prepared for:

NAVAL ANALYSIS PROGRAMS (CODE 462)
OFFICE OF NAVAL RESEARCH
ARLINGTON, VIRGINIA 22217

CONTRACT N00014-71-C-0417
Task No. NR 274-008-44

SRI Project 1319-10

Reproduction in whole or in part is permitted for any purpose of the United States Government.

Distribution limited to DOD agencies only: Test and Evaluation — 19 July 1973. Other requests for this document must be referred to the Office of Naval Research (Code 462).

Approved by:

LAWRENCE J. LOW, *Director*
Naval Warfare Research Center

ERNEST J. MOORE, *Executive Director*
Engineering Systems Division

ABSTRACT

This document in two volumes is a guide to fire support mix evaluation techniques. The Guide results from research conducted with the overall objective of identifying a comprehensive methodology for evaluating fire support system mixes.

Volume 1 (unclassified) contains the Guide proper in four parts. Part I contains the analysis of the fire support function and process, including definitions, descriptions, future trends, key elements, parameters, and interrelationships with other combat functional areas. Part II describes existing fire support methodologies, identifies their strong and weak points, and suggests alternative approaches. Methodologies are assessed from both an overall and a key element viewpoint. Part III synthesizes the salient methodological issues. Part IV contains suggested procedures for use of an analyst in the conduct and management of a fire support mix evaluation study, relationship of existing and alternative techniques to key elements, strengths and weaknesses of existing methodologies, how existing studies answer fire support questions, criteria for evaluating studies, and pitfalls to be avoided. Also in Volume 1 are Appendices A and B, which provide a listing of system parameters and a bibliography.

Volume 2 is classified and consists entirely of Appendix C, summary analyses of 14 selected fire support studies used as the basic data base.

PREFACE

This document constitutes the end product of a research study conducted to evaluate fire support mix methodology techniques. The project was sponsored by the Director, Naval Analysis Programs, Office of Naval Research, as part of a continuing research program in support of amphibious warfare operations. Mr. R. H. Dickman was the ONR Project Scientific Officer. Representatives of the Marine Corps Development and Education Command, as a potential user of the document, provided useful counsel during the course of the study.

The research effort was performed by Stanford Research Institute's Naval Warfare Research Center, Mr. L. J. Low, Director. Mr. R. J. McNicholas was the project leader. He was assisted principally by Mr. F. L. Crane, who performed the bulk of the analysis of fire support methodologies and analyzed many of the selected fire support studies used as the data base.

Other personnel of Stanford Research Institute contributed to the accomplishment of the study. Mr. L. S. Peters made significant contributions in the area of overall fire support methodology and provided particular expertise with respect to aviation matters. Mr. B. Jackson (consultant) analyzed many of the selected fire support studies used as the data base. Mr. J. A. Saxten assisted in the definition and description of fire support and the determination of future trends and influences. Mr. W. Schubert contributed the cost analysis assessment. Messrs. W. L. Edwards and H. B. Wilder, Jr. provided expertise with respect to logistic alternatives.

The Guide is in two volumes. Volume 1 is unclassified and contains the Guide proper, a glossary, and two appendices. Volume 2 is classified and contains the third appendix consisting of the summary analyses used as the data base for the preparation of the Guide.

CONTENTS

DD Form 1473	iii
ABSTRACT	v
PREFACE	vii
LIST OF ILLUSTRATIONS	xvii
LIST OF TABLES	xix
SUMMARY	S-1
INTRODUCTION TO THE GUIDE	1

Part I--ANALYSIS OF FIRE SUPPORT

I INTRODUCTION	I-3
II DEFINITION AND DELIMITATION OF FIRE SUPPORT	I-5
A. Purpose and Definition	I-5
B. Components	I-5
C. Functions	I-7
D. Close and Deep Support	I-8
E. Boundaries	I-9
III CHARACTERISTICS AND CAPABILITIES OF SUPPORTING ARMS . . .	I-13
A. Roles	I-13
B. Characteristics	I-13
C. Description of Elements of Each Supporting Arm . . .	I-15
1. Elements of the Artillery Weapons System . . .	I-15
2. Elements of the <u>Air Support Weapons System</u> . .	I-17
3. Elements of the <u>Naval Gun Weapons System</u> . . .	I-18
4. Elements of the Armored Combat Weapons System .	I-19

III CHARACTERISTICS AND CAPABILITIES OF SUPPORTING ARMS (Continued)

D.	Comparative Capabilities	I-19
E.	Weapon System Selection Process and Criteria for Assignment of Fire Missions	I-21
IV	FUTURE TRENDS AND INFLUENCES	I-27
A.	Operational Environment	I-28
B.	Threat Characteristics	I-28
C.	Infantry Combat Systems (To Be Supported)	I-29
D.	Supporting Arms Weapons (As Part of Firepower System)	I-30
E.	Other Functional Areas	I-30
	1. Intelligence	I-30
	2. Command, Control, and Communications	I-31
	3. Mobility	I-31
	4. Logistics	I-31
V	KEY ELEMENTS FOR SYSTEMS ANALYSIS	I-33
A.	Fire Support As a System	I-33
	1. Constituent Parts of Fire Support	I-33
	2. Fire Support Mix Methodology Elements	I-35
B.	Fire Mission Generation	I-36
	1. Operational Environment	I-38
	2. Threat	I-38
	3. Fire Mission Generation Subelements	I-38
C.	Fire Mission Allocation	I-40
	1. Weapon Mix Generation	I-40
	2. Weapon System Performance	I-41
	3. Weapon Support System Performance	I-41
	4. The Allocation Function	I-41
D.	Fire Support System Effectiveness Analysis	I-42
	1. Quantitative Measures of Effectiveness	I-42
	2. Qualitative Measures of Effectiveness	I-42
E.	Fire Support System Cost Analysis	I-43
F.	Fire Support System Mix Preference Selection	I-43

VI	FIRE SUPPORT SYSTEM PARAMETERS	I-45
VII	INTERRELATIONSHIPS OF FUNCTIONAL AREAS	I-47
A.	Intelligence	I-48
B.	Logistics	I-49
C.	Command, Control, and Communications	I-49
D.	Mobility	I-50

Part II--ASSESSMENT OF FIRE SUPPORT METHODOLOGIES

I	INTRODUCTION	II-3
II	THE OVERALL APPROACH	II-9
A.	Techniques in Use	II-9
1.	Center for Naval Analyses (CNA) Study	II-9
2.	Lockheed Dynamic Effectiveness Model Study (DEMS)	II-10
3.	Lockheed/USMC Study	II-11
4.	USMC Fire Support Requirements Study	II-12
5.	Naval Weapons Laboratory System	II-13
6.	Ohio State University Study--DYNTACS	II-13
7.	University of Michigan Study	II-15
8.	Research Analysis Corporation (RAC) Study	II-16
9.	Stanford Research Institute (SRI)/Balanced Force Requirements Analysis Model (BALFRAM)	II-17
10.	Stanford Research Institute/Marine Corps Attack and Fighter Aircraft Requirements (MAFAR)	II-18
11.	U.S. Army Strategy and Tactics Analysis Group (STAG) Study/LEGION	II-19
12.	U.S. Army Combat Developments Command (USACDC) Study/Legal Mix	II-19
13.	Weapons Systems Evaluation Group (WSEG) Study	II-20
B.	Evaluation of Strengths and Weaknesses	II-23
C.	Alternatives	II-25
1.	The Fire Support System Aggregated Model	II-26
2.	The Key Element Model for the Fire Support System	II-28
3.	Supporting Models for the Fire Support System Model	II-34

III	FIRE MISSION GENERATION	II-35
A.	Techniques in Use	II-35
1.	Fire Support Actual Target Arrays	II-36
2.	Fire Support Target/Mission List	II-39
B.	Evaluation of Strengths and Weaknesses	II-46
1.	Fire Support Target Arrays	II-46
2.	Fire Support Target/Mission List	II-51
C.	Alternatives	II-55
1.	Fire Support Target Array Generation	II-55
2.	Fire Support Target/Mission List Generation	II-60
IV	FIRE MISSION ALLOCATION AND FIRE SUPPORT SYSTEM EFFECTIVENESS	II-65
A.	Techniques in Use	II-65
1.	Mission Allocation	II-65
2.	System Effectiveness	II-67
3.	Support Models	II-76
B.	Evaluation of Strengths and Weaknesses	II-84
1.	Mission Allocation	II-85
2.	System Effectiveness	II-86
C.	Alternatives	II-90
1.	Mission Allocation	II-90
2.	System Effectiveness	II-90
3.	Weapons Effects	II-91
4.	Intelligence	II-91
5.	Logistics	II-92
6.	Command, Control, and Communications	II-93
7.	Mobility	II-94
V	FIRE SUPPORT SYSTEM MIX SELECTION	II-95
A.	Techniques in Use	II-95
1.	Center for Naval Analyses Study	II-98
2.	Lockheed/DEMS	II-99
3.	Lockheed/USMC	II-100
4.	Naval Weapons Laboratory, Dahlgren, Study	II-101
5.	U.S. Army Combat Developments Command/Legal Mix IV	II-103

V	FIRE SUPPORT SYSTEM MIX SELECTION (Continued)	
B.	Evaluations of Strengths and Weaknesses	II-104
1.	General Weaknesses	II-104
2.	The Naval Weapons Laboratory Approach	II-107
C.	Alternatives	II-108
1.	General	II-108
2.	Cost/Effectiveness Analyses	II-109
VI	COST ANALYSIS	II-115
A.	Techniques in Use	II-115
1.	Type of Costs	II-115
2.	Cost Coverage	II-117
3.	Cost Sources	II-118
4.	Cost Phasing	II-118
5.	Time Period	II-118
6.	Terminal/Residual Value	II-119
7.	Discounting	II-119
8.	Inflation	II-119
9.	Cost Structure	II-120
10.	Multiple Use Cost Allocation	II-120
11.	Cost Uncertainty	II-121
12.	Sensitivity Analysis	II-121
13.	Cost Assumption	II-121
B.	Evaluation of Strengths and Weaknesses	II-122
C.	Alternatives	II-123
	REFERENCES	II-125

Part III--SYNTHESIS OF METHODOLOGICAL ISSUES

I	INTRODUCTION	III-3
II	INPUT DEFICIENCIES	III-5
A.	Availability	III-5
B.	Specific Deficiencies	III-6
1.	Scenarios	III-6
2.	Aggregated Measures of Performance	III-6
3.	Target Acquisition	III-7
4.	New Systems and Techniques	III-7

II	INPUT DEFICIENCIES (Continued)	
	C. Sensitivity Analyses	III-7
III	OTHER METHODOLOGICAL ISSUES	III-9
	A. Overall Approach	III-9
	1. Model Hierarchy--Unified or Compartmentalized	III-9
	2. Two-Sided Versus One-Sided Models	III-10
	3. The Need for Sensitivity Analyses	III-11
	4. The Inclusion of Uncertainty	III-11
	B. Fire Mission Generation	III-12
	1. Realistic Target Arrays	III-12
	2. Translation of Actual Target Array to a Target/Mission List	III-13
	C. Fire Mission Allocation	III-13
	D. Fire Support System Effectiveness	III-14
	E. Fire Support System Mix Preference Selection	III-14
	1. Measures of Effectiveness	III-14
	2. Cost/Effectiveness Analyses	III-15
	3. Risk	III-16
	F. Cost Analysis	III-16
	G. Future Trends and Influences	III-17
	1. Operational Environment	III-17
	2. Threat	III-18
	3. Infantry Combat System/Supporting Arms Weapons.	III-18
	4. Other Combat Functional Areas	III-18

Part IV--PROCEDURES FOR A FIRE SUPPORT MIX STUDY

I	INTRODUCTION	IV-3
II	STEPS IN A FIRE SUPPORT MIX EVALUATION STUDY	IV-5
	A. The Systems Approach	IV-5
	B. Specific Elements of a Mix Methodology	IV-6

III	RELATIONSHIP OF EXISTING AND ALTERNATIVE TECHNIQUES TO ELEMENTS OF THE FIRE SUPPORT MIX EVALUATION METHODOLOGY	IV-9
A.	Matrix Relating Existing and Alternative Techniques to Key Elements of the Fire Support Problem	IV-9
B.	Matrix Relating Existing and Alternative Techniques to Supporting Models	IV-9
IV	STRENGTHS AND WEAKNESSES OF EXISTING METHODOLOGIES	IV-13
V	HOW EXISTING STUDIES ANSWER FIRE SUPPORT QUESTIONS	IV-15
VI	CRITERIA FOR EVALUATING A COMPLETED STUDY	IV-21
VII	PITFALLS IN FIRE SUPPORT MIX STUDIES	IV-23
	GLOSSARY	IV-25
APPENDICES		
A	LISTING OF FIRE SUPPORT SYSTEM PARAMETERS	A-1
B	BIBLIOGRAPHY	B-1
	DISTRIBUTION LIST	D-1
C	VOLUME 2: SUMMARY ANALYSES OF SELECTED FIRE SUPPORT STUDIES (U)	

Volume 2 is classified SECRET

ILLUSTRATIONS

S-1	Approach to the Development of the Guide	S-2
S-2	Hierarchy of Models/Procedures for Fire Support Methodologies	S-7
1	Flow Diagram of Weapon Selection Process Sequence	I-25
2	Conceptual Fire Support System	I-35
3	Interrelationships of Key Elements of Fire Support Methodology	I-37
4	Interrelationships of Combat Functional Areas	I-48
5	Hierarchy of Models/Procedures for Fire Support Mix Studies	II-5
6	Schematic for the Dynamic Fire Support System Model (DYFSS)	II-30
7	Example of the Role of Uncertainty in Mix Selection	II-112
A-1	Interrelationships of Key Elements of Fire Support Methodology	A-5
A-2	Operational Environment Input Factors	A-6
A-3	Threat Input Factors	A-7
A-4	Fire Mission Generation Parameters	A-9
A-5	Weapon Mix Generation Parameters	A-11
A-6	Weapon System Performance Factors	A-13
A-7	Weapon Support System Performance Factors	A-15
A-8	Fire Mission Allocation Parameters and Factors	A-16
A-9	Analysis Measures for Fire Support System Effectiveness	A-17
A-10	Cost Analysis Parameters	A-18
A-11	Preference Selection Criteria for Fire Support System Mix	A-19

TABLES

S-1	Synopsis of the Guide	S-4
S-2	Strengths and Weaknesses of Existing Methodologies	S-6
1	Roles of Supporting Arms	I-13
2	Characteristics of Supporting Arms	I-14
3	Comparative Capabilities of Supporting Arms (Current) . .	I-20
4	Factors Determining Supporting Arms Capabilities	I-21
5	Criteria for Use of Naval Gunfire and/or Offensive Air Fire Support	I-23
6	Summary of Techniques Used in Existing Studies	II-22
7	Strengths and Weaknesses of Existing Fire Support Methodologies	II-24
8	Summary of Existing Techniques for Fire Support Target Array Generation	II-37
9	Summary of Techniques Used to Develop the Target/ Mission List from the Fire Support Target Array	II-40
10	Target/Mission List Information	II-44
11	Strengths and Weaknesses of Target Array Generation Techniques	II-47
12	Summary of Some Target Array Statistics	II-54
13	Summary of Mission Allocation Techniques in Use	II-66
14	Summary of Target Characteristics in Current Studies . . .	II-69
15	Artillery Systems in Fire Support Studies	II-71
16	Naval Gun Systems in Fire Support Studies	II-72
17	Aircraft in Fire Support Studies	II-72
18	Summary of Damage Determination Techniques in Current Studies	II-73
19	Neutralization/Suppression in the Fire Support Studies . .	II-77

20	Summary of Logistic Modeling Techniques in Studies Reviewed	II-80
21	Summary of the Treatment of Mobility in the Reviewed Studies	II-83
22	Measures of Effectiveness and Measures of Effort Used in Fire Support Studies	II-97
23	Costing Techniques Used in Past Studies	II-116
24	Matrix Relating Existing and Alternative Methodologies to Key Elements of Fire Support Problem	IV-10
25	Matrix Relating Existing and Alternative Methodologies to Fire Support Supporting Models	IV-11
26	Strengths and Weaknesses of Existing Methodologies	IV-14
27	Fire Support Questions and Applied Methodologies	IV-16

SUMMARY

Objective

The objective of the research leading to this Guide was to identify a comprehensive methodology for evaluating fire support mixes. The Guide provides extensive background material for the fire support analyst, outlines the procedures for performing a study, and provides the basic structure of a fire support mix evaluation methodology.

The motivation for the development of this Guide arose from the recognition of the importance of fire support and the inadequacies prevalent in existing fire support study methodologies. The need was evident for a guide that addresses all aspects of the fire support system; that catalogs existing studies and methodologies; and that suggests alternative techniques, as appropriate.

Approach

The approach taken consists of four tasks; their interrelationships are depicted in Figure S-1. A review of the nature of fire support comprised Task I and provided the background needed for the descriptive and analytical material contained in Part I of the Guide.

Task II was to review existing methodologies. This thorough review of 14 studies provided the background and detailed information needed for Task III, where the strengths, weaknesses, and gaps in existing methodologies are identified. Task III also provided alternative techniques to correct the deficiencies in existing methodologies. In Task IV all this information was combined in a format suitable as a guide for the fire support system mix analyst.

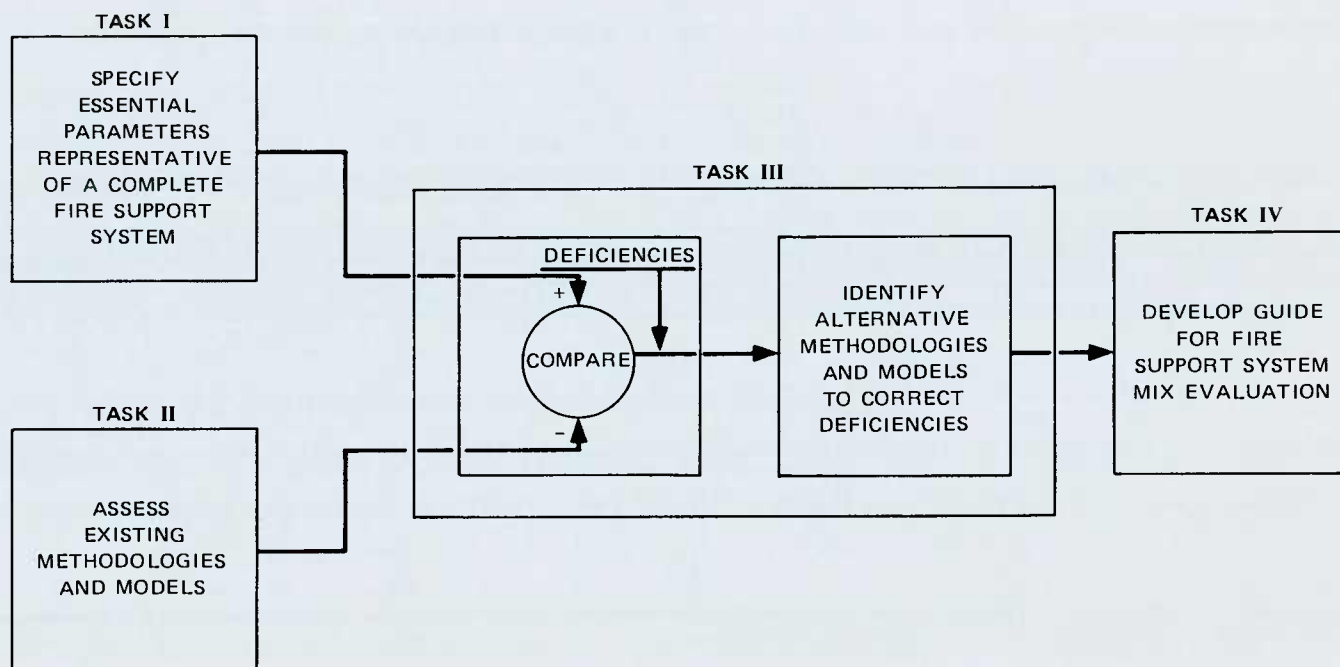


FIGURE S-1 THE APPROACH TO DEVELOPMENT OF THE GUIDE

Results

The Guide is the result of this research effort. It provides a comprehensive discussion of the nature of fire support and mix evaluation. Table S-1 presents a synopsis of the material contained in the Guide. Part I analyzes the many elements that make up fire support from the point of view of the analyst desiring to understand and model the fire support function. Fire support is defined and delimited and then separated into the key elements that allow its analysis from a systems analysis point of view.

These key elements provide the framework around which a comprehensive methodology for fire support analyses is built in Part II. Part II contains evaluations of 14 major studies that address either the fire support question or related methodological issues. It also presents alternatives to the techniques used in existing studies, particularly in areas of weakness.

Part III summarizes the methodological issues identified in Part II so that the analyst can focus his efforts on these major problem areas.

Part IV outlines suggested procedures for the analyst to follow in a fire support mix study, along with a synopsis of how existing studies approach the fire support problem. It also discusses eight pitfalls to which fire support methodologies are particularly susceptible.

There are three appendices to the Guide. Appendix A provides a detailed breakdown of the fire support system in terms of the parameters that characterize it. This breakdown can serve as a checklist against which the analyst evaluates the completeness of a methodology under consideration for a fire support study.

Appendix B is a bibliography of 35 references that deal directly with fire support or related methodological issues.

Table S-1

SYNOPSIS OF THE GUIDE

<p>Part I</p> <p>Analysis of Fire Support</p>	<p>Fire support--definition and delimitation</p> <p>Supporting arms characteristics</p> <p>Future trends and influences</p> <p>Key element breakout for systems analysis</p> <p>System parameters</p> <p>Interrelationships to functional areas</p>
<p>Part II</p> <p>Assessment of Fire Support Methodologies</p>	<p>Evaluation of 14 fire support studies and methodologies</p> <p>State of the art in fire support mix evaluation</p> <p>Alternative approaches and techniques</p>
<p>Part III</p> <p>Synthesis of Methodological Issues</p>	<p>Synopsis of key methodological deficiencies</p> <p>Input deficiencies</p> <p>Technique needs</p>
<p>Part IV</p> <p>Procedures for a Fire Support Mix Study</p>	<p>Steps to be taken</p> <p>Existing/alternative techniques and the key elements of the mix methodology</p> <p>How existing studies address fire support questions</p> <p>Pitfalls to be avoided</p>

Appendix C comprises Volume II, which is classified Secret. It contains detailed reviews of the 14 studies selected for evaluation in this study. The studies range from comprehensive studies embracing the entire fire support system to fairly simple studies that consider only parts of the system or contain a relevant methodology. The reviews provide valuable background information for the analyst in understanding the evaluation in Part II.

Two key results of the work leading to this Guide are:

- (1) The identification of the state of the art of fire support mix evaluation methodologies.
- (2) The framework for a comprehensive fire support mix evaluation methodology.

Table S-2 summarizes the state of the art and it lists the strengths and weaknesses that pervade the 14 studies that formed the data base for the Guide. The strengths and weaknesses associated with the overall study approach and with each of the key methodological elements of Fire Mission Generation, Mission Allocation, System Effectiveness, Mix Selection, and Cost Analysis are tabulated. The entries in this table serve as indicators of where methodological development must be emphasized in future studies and where adequate existing techniques already exist.

Figure S-2 addresses the second key result. The need for an overall methodology that provides for the interactions among the many elements of the fire support system is clear. The methodological framework in Figure S-2 does this. It shows a hierarchy of three levels of models--all interacting. The highest level model represents a high degree of aggregation. Its prime function is to carry out sensitivity analyses, to check assumptions made at the other modeling levels, and to interpolate and extrapolate results obtained at the other, less aggregated levels. This model, which is not an existing model, has been designated the Fire Support System Aggregated Model (FSSAM).

Table S-2

STRENGTHS AND WEAKNESSES OF EXISTING METHODOLOGIES

Methodology Element	Strengths	Weaknesses
Overall approach	<p>Good mission allocation procedures</p> <p>Adequate and varied weapon effects models</p>	<p>Unrealistic mission lists</p> <p>Paucity of two-sided models</p> <p>Uncertainty often ignored</p> <p>Little sensitivity analysis</p> <p>Target acquisition often ignored</p> <p>C³ inadequately handled</p> <p>Logistics support handled simplistically, if at all</p> <p>Infrequent use of optimization techniques for mix selection</p> <p>Lack of standard MOEs</p>
Fire mission generation	<p>War games</p> <p>High degree of realism resulting from human judgment</p> <p>Great detail possible</p> <p>Two-sided</p> <p>Historical data</p> <p>A measure of realism based on the use of actual battle data</p> <p>Gives numbers and ranges of target types</p> <p>Ease of use</p>	<p>War games</p> <p>Many players and controllers needed</p> <p>Very time and money consuming</p> <p>Limited flexibility for excursions</p> <p>Gives single sample of a random process</p> <p>Historical data</p> <p>Less realism than war games</p> <p>One-sided in use</p> <p>Shortage of adequate data</p> <p>Possibility of biased data</p> <p>Difficult to adapt to new systems and concepts</p>
Mission allocation	Generally well modeled	Lack of a consistent set of criteria for allocation
System effectiveness	<p>Generally thoroughly modeled</p> <p>Good supply of weapon effects data</p>	<p>Weak supporting models for intelligence, C³, and logistics</p> <p>Little treatment of uncertainty</p>
Mix selection	<p>NWL's fixed effectiveness analytical model</p> <p>Lockheed/USMC's qualitative/quantitative approach</p>	<p>Proliferation of MOEs</p> <p>Few sensitivity analyses</p> <p>Risk ignored</p>
Cost analysis	<p>Program cost models</p> <p>Many well-developed cost techniques</p>	<p>Little wartime costing</p> <p>Little time-phased costing</p> <p>No treatment of uncertainty</p> <p>Difficulty of multimission costing</p>

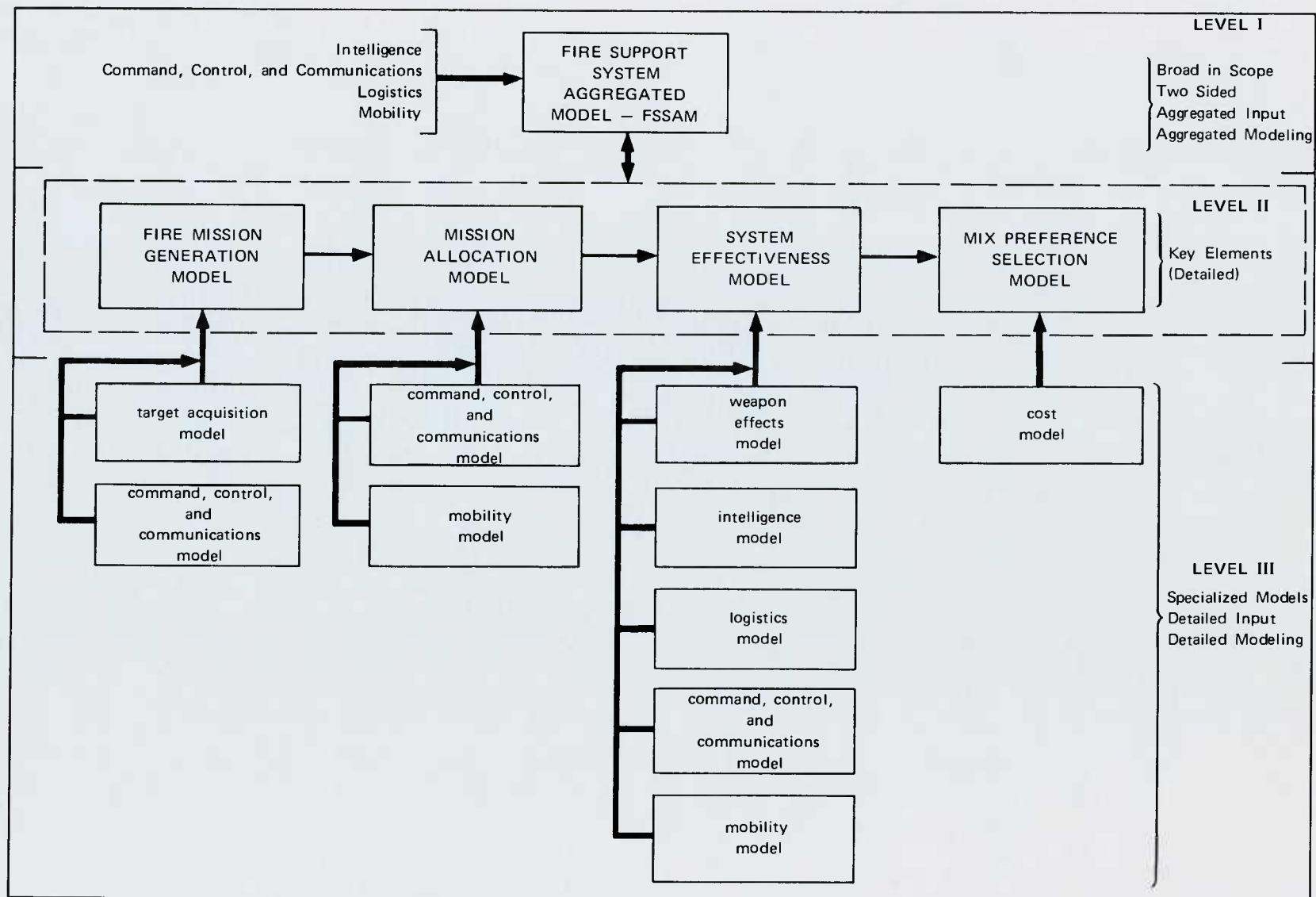


FIGURE S-2 HIERARCHY OF MODELS/PROCEDURES FOR FIRE SUPPORT MIX STUDIES

The second-level model is the central analytical tool for the mix evaluations. It is used for the bulk of the analysis. It differs from the highest level model, FSSAM, primarily by the greater degree of detail in which it models the fire support system. Two approaches to modeling at this level are discussed and weighed in the guide--a unified approach and a compartmentalized approach. The unified approach places greater emphasis on the interactions among key elements than the compartmentalized approach does.

The third-level models are very detailed and are designed to provide support to the second-level models in the areas of intelligence; weapons effects; logistics; mobility; cost; and command, control, and communications. These models are highly specialized, but in most cases modified versions of existing models could meet the requirements at this level.

Potential Users

This Guide should be of prime value to Navy and Marine Corps analysts engaged in the conduct of or the generation of fire support studies relating to optimum mixes of supporting arms.

It should also provide a convenient, valuable source document for the following:

- Navy and Marine Corps officers involved in the planning of and establishing requirements for future actual fire support systems.
- Any analyst, military or civilian, involved in a fire support study who desires to ascertain the relationship of his particular problem to fire support as a whole.
- Reviewers of fire support studies by providing a broad background in fire support mix evaluation techniques, as well as a convenient set of criteria for review.

INTRODUCTION TO THE GUIDE

This document is a Guide to fire support mix evaluation techniques. The Guide results from research conducted with the overall objective of identifying a comprehensive methodology for evaluating fire support system mixes. Emphasis has been given in the research to existing modeling techniques and to the adequacy of these techniques for application to analysis of fire support requirements in future operational environments of the mid- and long-range time periods.

The genesis of the research effort has been the importance attached to the effective use of firepower in future operations, coupled with a lack of a fully comprehensive methodology to evaluate adequately candidate fire support systems. Navy and Marine Corps future concepts, especially the Marine Corps Long Range Concept, emphasize the need for improving all elements that relate to achieving increased fire support effectiveness. To do this, the analytical means must be available to interrelate and evaluate all of these elements. Although the problem of fire support has been subjected to numerous studies, the efforts are judged as not having yet produced an adequate comprehensive overall methodology.

It is also felt that a logical basis is needed not only for establishing the performance interrelationships among aviation, artillery, naval shore fire, and armor (used in a fire support role), but also for quantifying the firepower effectiveness improvements that can be made through enhanced: intelligence (improved targeting), logistics (sea basing and seaborne mobile logistics systems offering better supply and maintenance), mobility (the capability for extended vertical

deployment), and command and control (more accurate position location and automated fire direction and communications systems). The many models already developed represent some of these fire support aspects; however, they do not address all the significant parameters and have not been incorporated into a fully comprehensive methodology that encompasses the complete fire support system.

In the conduct of the research effort, current Navy Strategic Studies, Marine Corps Long Range Studies, Navy and Marine Corps Long Range Plans, and recent SRI/NWRC studies have been used as the basis for defining the elements of fire support, identifying significant parameters, and establishing interrelationships. Studies pertinent to Navy/Marine Corps fire support, such as the recently completed MAF and MAB Fire Support Studies at the Naval Weapons Laboratory, Dahlgren, and other selected Navy and Army studies were used as a data base for determining the techniques actually used and for evaluating the strengths and weaknesses of those techniques.

The results of this research into fire support techniques are contained in this Guide. The Guide describes the available techniques, identifies their uses, evaluates their strengths and weaknesses, and delineates alternative techniques. The Guide is organized as follows:

Part I--Analysis of the fire support function and process, including definitions, descriptions, future trends, key elements, parameters, and interrelationships with other combat functional areas. This part provides the background material needed by the analyst to analyze and model fire support.

Part II--Description of existing fire support methodologies, identification of their strong and weak points, and suggestions for alternative approaches. Methodologies are assessed from both an overall and a key element viewpoint. This part provides the analyst with knowledge of how others have attacked the fire support problem, the essential elements of existing and proposed methodologies, and insight into the difficulties and possible solutions.

Part III--Synthesis of the methodological issues as uncovered in Parts I and II. This Part summarizes the salient methodological issues raised in previous parts of the report.

Part IV--Suggested procedures for use of an analyst in the conduct and management of a fire support mix evaluation study, including the basic steps of a study; relationship of existing and alternative techniques to key elements; strengths and weaknesses of existing methodologies; how existing studies answer fire support questions; criteria for evaluating studies; and pitfalls to be avoided. This part encapsulates in brief, convenient form useful information for the analyst in the conduct of a fire support mix evaluation.

Appendices--Appendices A and B in this unclassified volume provide a listing of system parameters and a bibliography. Appendix C, in a separate, classified Volume 2, provides the summary analyses of the selected fire support studies used as the basic data base and described in Part II of Volume 1. These studies range from comprehensive studies embracing the entire fire support system to fairly simple studies that consider only parts of the system or contain a relevant methodology.

Part I

ANALYSIS OF FIRE SUPPORT

I INTRODUCTION

The purpose of Part I of the Guide is to analyze the fire support process from the viewpoint of the analyst who desires first to understand the fire support function and then to model the process. The analysis begins with the definition and description of fire support, including significant future trends and influences. The fire support process is then separated into its key elements, each element is described and discussed, and the parameters associated with each of the elements are identified.

The final portion of the analysis examines the relationships between fire support and other functional areas of combat. This last portion gives recognition to the fact that fire support, although a major part of the functional area of firepower, does not exist independently of the other functional areas: intelligence, command and control, mobility, and logistics. As will be seen, the partition of the fire support process into key elements facilitates the identification of these relationships.

II DEFINITION AND DELIMITATION OF FIRE SUPPORT

A. Purpose and Definition

The term "fire support"* embraces the employment of a variety of weapons to provide supporting fire to ground units in combat. A more precise and relevant term to describe these weapons is "supporting arms," which is defined in JCS Pub 1[†] as air, naval, and artillery weapons of all types when they are employed to provide support fire for ground units. Since the amphibious operation is the type of operation of primary interest in this study, the further qualification may be added of "...when employed to provide support fire for ground units in amphibious operations." It is to be further observed that the term fire support denotes specifically a function/role rather than a weapons system(s). The weapons, when used as supporting arms (per the foregoing definition), fulfill the function/role of fire support.

B. Components

The three general types of supporting arms employed in the fire support role may be further described as follows:

- (1) Air--The air weapon system consists of the carrier or land base, the aircraft, the aircraft weapon delivery subsystem, and the ordnance.

* The term "fire support" is not defined as such in JCS Pub 1. "Supporting fire" is defined therein as "fire delivered by supporting units to assist or protect a unit in combat."

[†]"Department of Defense Dictionary of Military and Associated Terms," JCS Pub 1, The Joint Chiefs of Staff, Washington, D.C. (1 January 1972).

- (2) Naval--The naval combat ship weapon system consists of the ship platform, the gun/missile mount(s) and associated fire control subsystem, and the ammunition.
- (3) Artillery--The artillery weapon system consists of the gun, howitzer, missile launcher, mortar, associated fire control subsystem, and the ammunition.

The Marine Corps in its GOR on supporting arms^{*} has expanded the scope of the term "supporting arms" to include two additional types of weapon systems: armored combat and special purpose. The term as now used in the GOR embraces all methods of neutralizing and destroying designated ground targets (fixed and mobile, hard and soft, point and area) in support of Marine landing forces in amphibious assault and sustained combat operations ashore to meet the estimated threats. The only Marine Corps weapons excluded from the scope of the term are the individual and man-portable weapons of infantry systems, antiair warfare weapons, and unconventional weapons. The two additional types of supporting arms may be further described as follows:

- (4) Armor--The armored combat weapons system consists of armored combat vehicles (which include tanks and future substitutes therefor and armored amphibians that mount gun systems) to provide mobile, protected firepower to close with and destroy enemy ground forces and strengthen antimechanized defenses.
- (5) Special purpose--The special purpose weapons systems consist of area denial weapons, psychological operations, and riot control weapons.

Of the two types, only the armor type lends itself to inclusion in the fire support mix evaluation under examination. Hence, the special purpose

*"General Operational Requirement (GOR), SPA-1, Supporting Arms," Department of the Navy, Headquarters U.S. Marine Corps, Washington, D.C. (April 1972), SECRET/NOFORN.

weapons system type will be set aside as far as this study is concerned, leaving four principal types of weapons systems for consideration.*

C. Functions

The function of fire support (i.e., supporting fire) is further subdivided with respect to the proximity of the target to friendly forces:

- Close Supporting Fire, defined in JCS Pub 1 as "Fire placed on enemy troops, weapons, or positions which, because of their proximity, present the most immediate and serious threat to the supported unit."
- Deep Supporting Fire, defined in JCS Pub 1 as "Fire Directed on objectives not in the immediate vicinity of our forces, for neutralizing and destroying enemy reserves and weapons, and interfering with enemy command, supply, communications, and observations."

The terms used to describe the functions of each of the four supporting arms types employed in a fire support role are the following:

- Offensive Air Fire Support (OAFS)--Since the term "air support" alone embraces all forms of support given by air forces to forces on land or sea,[†] including observation, reconnaissance, and tactical air lift, it is necessary to designate the fire delivery portion as "offensive air fire support." Offensive air fire support includes both close and deep supporting fires. However, the term "close supporting fires," when applied to air action, becomes close air support (CAS) or, precisely, "close air fire support," defined in JCS Pub 1 as "Air action against hostile targets which are in close proximity to friendly forces and which require detailed integration of each air mission with the fire and movement of those forces."

* In addition, since the bulk of the research in this study has been devoted to evaluating existing mix studies and since few of these treat armor in any detail, armored combat receives significantly less attention here than the three traditional supporting arms.

[†] JCS Pub 1.

- Naval Gunfire Support (NGFS)--The term previously adopted for use in Marine Corps long range documentation to embrace a broader spectrum of weapons than guns was "naval shore fire support." Thus, guided missiles were easily within the connotation of the term. However, current usage* stays with the older term of naval gunfire support, which is defined to include all types of ship-based, surface-launched weapons usable in the fire support role, including guns, rockets, and missiles. NGFS comprises both close- and deep-supporting fires.
- Artillery Fire Support (AFS)--This is also called "field artillery support," or more simply just "artillery." It includes both close and deep supporting fires. As will be noted later, artillery is especially suited for providing the continuous close support requirements of ground forces.
- Armored Combat Fire Support (ACFS)--This is highly mobile protected fire employed primarily in a direct fire role. Its mission is to attack, disrupt, and destroy enemy forces through the use of firepower, shock effect, and maneuver. Within the Marine Corps it is provided currently by tanks; in the future it is planned to be provided by lightly protected armored vehicles having a high degree of maneuverability. The primary direct fire role is performed with the infantry and mechanized-motorized forces and for anti-tank protection of the landing force as the whole. These weapon systems may also be employed in an indirect fire role to supplement artillery. When so used, their operations are identified under current doctrine as being in the category of fire support. It would seem also desirable, in terms of fire support mix analysis methodology, to include in the fire support category the direct fire antitank protection operations, because these operations are also performed by offensive air support and naval gunfire support weapons when acting in fire support roles.

D. Close and Deep Support

The key question to be answered for the delimitation of fire support for study purposes is how far from friendly ground forces is such support

* GOR, SPA-1.

to be provided. As noted earlier, it embraces both close and deep support. Thus it starts at the near limit of close fire support and ends at the far limit of deep fire support. The near limit is defined solely by considerations of safety for the friendly forces being supported. The question of delimitation then becomes primarily one of how far out does deep support extend. Recent Marine Corps documentation* answers the question, in effect, by stating that the offensive air function is the provision of close and deep airborne fire support for the landing force by attacking and destroying or neutralizing enemy installations, equipment, supplies, and personnel within an amphibious objective area (AOA). It adds that offensive air may participate as directed in the destruction and interdiction of ground and surface targets outside the AOA. This latter application is not viewed as a determinant of need, but rather as the application of a capability designed to meet the primary need, i.e., within the AOA.

E. Boundaries

The size of the AOA is dictated by the requirements of each specific operation, but it must be sufficient to ensure accomplishment of the amphibious task force mission and to provide sufficient area for the conduct of necessary air, land, and sea operations.† For current operations, the typical area is one of 300-nmi radius centered on the beachhead and adjacent sea operating area. This radius is also consistent with near-term projections for deep support fire by offensive air. However, the projections for conducting operations in the long range period may extend to distances up to 500 nmi. Thus, since the long range period is of interest in this study, the longer radius of 500 nmi may be used as the range boundary for delimiting fire support.

* GOR, SPA-1.

† "Doctrine for Amphibious Operations," Naval Warfare Publication 22(B)/Landing Force Manual 01, Departments of Army, Navy, and Air Force. Washington, D.C. (1 August 1967), para. 200.

The delimitation of close fire support is also significant in the study because it presents coordination, control, and timing problems not involved in deep support. This is especially true of close air fire support, which by definition requires detailed integration of each mission with the fire and movement of the friendly forces on the ground. The far limit is set in current operating procedures by the designation of bomb lines on the ground. In amphibious operations the bomb line terminology is replaced by the fire support coordination line (FSCL). This line is defined* as one short of which aircraft do not attack ground targets except on request or approval of the appropriate ground commander and beyond which they may attack targets without clearance of the ground commander. The guideline for establishing the FSCL is stated† as being a short distance beyond the farthest point to which the landing force commander intends to send patrols and penetration forces (including helicopter-borne forces) or to maintain covering forces. It should be easy to identify on a map and easily recognized from the air. In the case of a deep penetration by helicopter-borne forces widely separated from the other friendly forces, FSCLs will be applied separately so they do not unduly restrict fire within the intervening spaces. The clearance authorization of the appropriate ground commander is obtained under current doctrine as follows:

- (1) Air strikes between the FEBA and the NFL‡ are cleared by the supported infantry battalion in whose zone of action the target is located.

*"Fleet Marine Force Manual (FMFM) 7-1 Fire Support Coordination," Department of the Navy, Headquarters U.S. Marine Corps, Washington, D.C. (18 August 1971), p. 56.

†Op. cit., p. 59.

‡No-Fire Line (NFL)--A line short of which artillery and naval gunfire support ships do not fire except on request of the supported unit commander, but beyond which they may fire at any time without danger to friendly forces. NFL is typically located short of the FSCL, i.e., closer to the FEBA.

- (2) Air strikes between the NFL and the FSCL are cleared by the Division FSCC.
- (3) Air strikes beyond the FSCL - unrestricted with respect to clearance by the ground commander.

Within the broad expanse of the total area as delimited by the outer boundary for deep support, the degree of concern of the ground commander tends to decrease as the distance increases. In ground warfare the different degrees of concern are usually expressed in terms of range/area bands identified as follows:

- Area of influence--The near area over which the ground commander is capable of influencing operations directly by maneuver of his forces or by fire from weapons normally under his control.
- Area of operation--The area extending beyond but including the area of influence in which the ground commander is required to conduct operations to accomplish his mission.
- Area of interest--The area extending beyond but including the area of operation in which the ground commander needs timely intelligence on enemy forces and activity that could develop into a threat to his operations.

The sizes of the three areas and distances involved vary with the size and composition of the force and the type of conflict. For example, estimates for an Army brigade in future operations under low intensity conflict situations indicate a radius in kilometers of 15, 30 to 125, and 70 to 270 for the areas of influence, operations, and interest, respectively.* For a division size Army force for a higher conflict intensity level, the area of influence would be larger but the upper limits for the areas of operations and interest would be no greater or possibly less than the brigade maximums shown.

*"Proceedings of the TACRAC I Land Warfare Symposium (U)," 17-19 February 1971, U.S. Army Aviation Center, Ft. Rucker, Alabama. Prepared and published by Research Analysis Corporation, McLean, Virginia (June 1971) SECRET/SPECIAL HANDLING, pp. 186-187.

The specific ranges identifying the degrees of interest cited above for typical ground warfare operations do not necessarily translate directly to amphibious assault operations, but the general approach seems pertinent and useful in examining methodological techniques.

III CHARACTERISTICS AND CAPABILITIES OF SUPPORTING ARMS

A. Roles

The fire support roles of the supporting arms are set forth in Table 1.

Table 1

ROLES OF SUPPORTING ARMS

Air*	Artillery	Naval Gunfire
Isolate the battle area Provide close air support to ground troops	Provide close and continuous fire support Provide rapid massed fires on critical points	Destroy or neutralize shore installations

* It is to be noted that air support fulfills roles other than fire support, consisting of gaining and maintaining air superiority, reconnaissance, and observation.

Source: FMFM 7-1.

B. Characteristics

The principal characteristics of each of the supporting arms are listed in Table 2 in terms of their relative advantages and disadvantages.

Table 2

CHARACTERISTICS OF SUPPORTING ARMS

Air		Artillery		Naval Gunfire	
Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages
Superior observation Ability to attack defiladed targets High speed and maneuverability Heavy destruction and neutralization capabilities Accuracy (under certain conditions) Long range capability High mobility and flexibility	Weather and visibility operational limitations Limited aircraft endurance Limited ammunition capacity Radio communications dependence Difficulty of target identification Large freefall bomb dispersion pattern Interference of other arms trajectories Air space restrictions Slow response time (except for air alert) Lack of continuity	Fast response time Massing capability Sustained action ability Continuous support ability Variable trajectory capability Surprise and shock effects Mobility	Nonavailability in initial assault phase Nonavailability during displacement Heavy weight for helicopter transportability Position space requirements affecting entry into combat Heavy ammunition logistic support requirements	Good mobility Accuracy of precision fire control equipment Possible variety of weapons Good variety of ammunition High muzzle velocity for penetration High rates of fire	Hydrography limitations affecting ship location Difficulty of fixing ship position accurately Weather and visibility operational limitations Changing gun target line affecting troop safety Large range dispersion pattern affecting troop safety Flat trajectory limitations Limited ship magazine capacity Radio communications dependence

Source: FMFM 7-1.

C. Description of Elements of Each Supporting Arm

1. Elements of the Artillery Weapons System*

a. Target Acquisition

This element of the artillery system detects and reports the location and composition of targets, initiates requests for fire, and conducts adjustment of fire as necessary. Historically, this function has been performed by the forward observer who accompanies the Marine rifle company. There is an evolution in process to combine the request for fire and conduct of adjustment for artillery with that of naval gun-fire and air strike. The success of STINGRAY operations in Vietnam has given impetus to this movement, and the MIFASS effort is assessing integrated TACT--Target Acquisition and Control Teams. The MARSAS effort, in consonance with the long range plan, shows a changing role for infantry units that emphasizes target acquisition and control of fires. This stress on the infantry elements to identify the target and to call for the application of fire will help satisfy the generic requirement for the precise application of firepower in the exact amount needed for the situation. An additional facet to target acquisition is the large variety of devices now available to assist in acquiring targets. The Marine Corps recognizes that these devices, which range from remotely emplaced sensors to radars to night vision devices, comprise a system, all parts of which assist in the target acquisition function. Many of these devices will be external to the artillery system as such.

b. Fire Control

Once targets are acquired, certain targets must be selected for attack, units must be designated to fire, ammunition must be allocated,

* For additional description see Fleet Marine Force Manuals "FMFM 7-1 Fire Support Coordination" and "FMFM 7-4 Field Artillery Support."

and requests for fire must be converted into firing data and commands. These actions constitute tactical and technical fire direction and generally take place at the fire direction center. Automation is being used to speed up this process. The MIFASS test bed is assessing where automation contributes to the system, where it only complicates the system, or where it militates against combat effectiveness.

c. Fire Unit

In the artillery, the basic fire unit has been the firing battery, usually consisting of four or six artillery pieces. This element actually executes the fire mission. It is here that the weapon characteristics such as accuracy, lethality, range, and mobility make their impact. The variety of ordnance in artillery--both projectile and fuzing types--adds to the flexibility of fires available.

d. Command and Control System

The key element of the artillery command and control system is the extensive communications network needed to accomplish tactical fire support. This network ties the previously listed elements together.

e. Support System

The support system provides the necessary ordnance by quantity and type, POL for the mobility means, and personnel and facilities for maintenance and repair.

2. Elements of the Air Support Weapons System*

a. Aircraft

This element consists of the aircraft itself and is usually described in terms such as payload, range, speed, and endurance. Vulnerability is also a very important characteristic.

b. Avionics

This element describes the sophisticated equipments placed in or on the aircraft that aid target acquisition, surveillance, navigation, fire control, and weapon delivery.

c. Aviation Ordnance

Aviation ordnance is the firepower itself; it is usually described in terms of kill probability and accuracy.

d. Control System

This element is the air command and control system; it allocates air resources to air elements and designates the mission and/or targets to the aircraft.

e. Support System

This element affects the readiness of aircraft by provisioning and maintaining the aircraft. Included is the type of basing facility for the air element.

* For additional description see Fleet Marine Force Manuals "FMFM 7-1 Fire Support Coordination," "FMFM 7-3 Air Support," and "FMFM 5-1 Marine Air."

3. Elements of the Naval Gun Weapons System*

a. Ship

The ship provides basic mobility and, by type, the amount of naval weaponry available.

b. Gun Mount and Associated Fire Control System

This element provides the actual delivery means (i.e., weapons) by caliber and, through the associated fire control system, the designated targets and firing data to hit them.

c. Ordnance

A variety of rounds and fuzes are available.

d. Organization for Fire Support Missions

This element provides the relationship between assigned gunfire support ships and supported landing force units. Ships placed in support provide the requested fire within their capability, but the ship positioning and method of delivery are left to the discretion of the ship's captain. The supported landing force unit selects the targets, the timing of fires on the target, and the adjustment of fires.

* For additional description see Fleet Marine Force Manuals "FMFM 7-1 Fire Support Coordination" and "FMFM 7-2 Naval Gunfire Support."

4. Elements of the Armored Combat Weapons System*

a. Vehicle

This element provides mobility. The platform must be sufficiently mobile to accompany the combat elements whenever they may be engaged and must have a high degree of survivability.

b. Weapon

This element provides the actual delivery means. Weapons may be rapid fire and omnidirectional with a day/night fire control system.

c. Ordnance

A variety of ordnance exists, including combination penetration/antipersonnel, flame, and terminal homing.

D. Comparative Capabilities

The capabilities of the supporting arms to provide fire support are described in comparative terms in Table 3. It is to be emphasized that a specific capability pertains only when the target is within range of the particular supporting arm.

The capabilities of the supporting arms to deliver effective fire support are determined by the factors listed in Table 4. The rankings shown are based on the preferences to be found in the referenced Marine Corps doctrinal publication,[†] but the numerical designations have been assigned by the SRI study team.

* For additional description see Fleet Marine Force Manual "FMFM 9-1 Tank Employment."

[†] FMFM 7-1.

Table 3

COMPARATIVE CAPABILITIES OF SUPPORTING ARMS (CURRENT)

Type of Mission	Air Support		Artillery Support		Naval Gunfire Support	
	Close	Deep	Close	Deep	Close	Deep
Destruction	Good	Best	Good (heavy artillery)	Good (heavy artillery)	Good (at short range)	Fair
Neutralization	Good (for short duration)	Good (for short duration)	Best	Best	Short periods	Short periods
Harassment	Limited application	Best	Excellent, especially in restricted visibility for small targets	Good	Limited application	Good for large targets
Interdiction	Limited application	Best at long range	Better than naval gunfire	Better than naval gunfire	Limited application	Good for visible targets
Illumination	Good (when scheduled and not for limited area)	Good (when scheduled and not for limited area)	Best	Best	Excellent	Excellent

Source: FMFM 7-1, para. 2209.

Table 4

FACTORS DETERMINING SUPPORTING ARMS CAPABILITIES

	Ranking		
	Air	Arty	NGF
Organization for combat (control arrangements and mission assignments)	3	1	2
Types of weapons and ammo availability	1	2	3
Accuracy of systems (measured against particular targets considering troop safety)	-	-	-
Mobility and range	1	2	3
Ability to mass fires	2	1	3
Rapidity in execution of fire mission	3	1	2
Vulnerability and continuity of action	3	1	2

Note: Numerical ranking indicates general order of comparative capability.

Source: FMFM 7-1, p. 39.

E. Weapon System Selection Process and Criteria for Assignment of Fire Missions

The normal order of preference in selecting a supporting arm for a particular fire mission is:

- (1) Artillery
- (2) Naval gunfire
- (3) Air.

Considerations affecting selection of a particular fire support means to perform a fire mission are as follows:

- (1) Out of range (applies primarily to artillery and naval gunfire)
- (2) Inclement weather
- (3) Ammunition shortage
- (4) Friendly troops in area
- (5) Communications
- (6) Restrictive terrain (e.g., defilade)
- (7) Weapons already engaged in higher priority mission
- (8) Time relay restriction
- (9) Most effective
- (10) Not ashore (applies to artillery)
- (11) Reaction time
- (12) Not capable of performing mission
- (13) On call (relates to availability)
- (14) Enemy air defense (denies use of air)
- (15) Not available due to receiving artillery fire

The criteria used to determine the use of naval gunfire and/or offensive air support can be summarized as shown in Table 5; it should be kept in mind that naval gunfire is usually preferred over air if both are available and can do the job equally well.

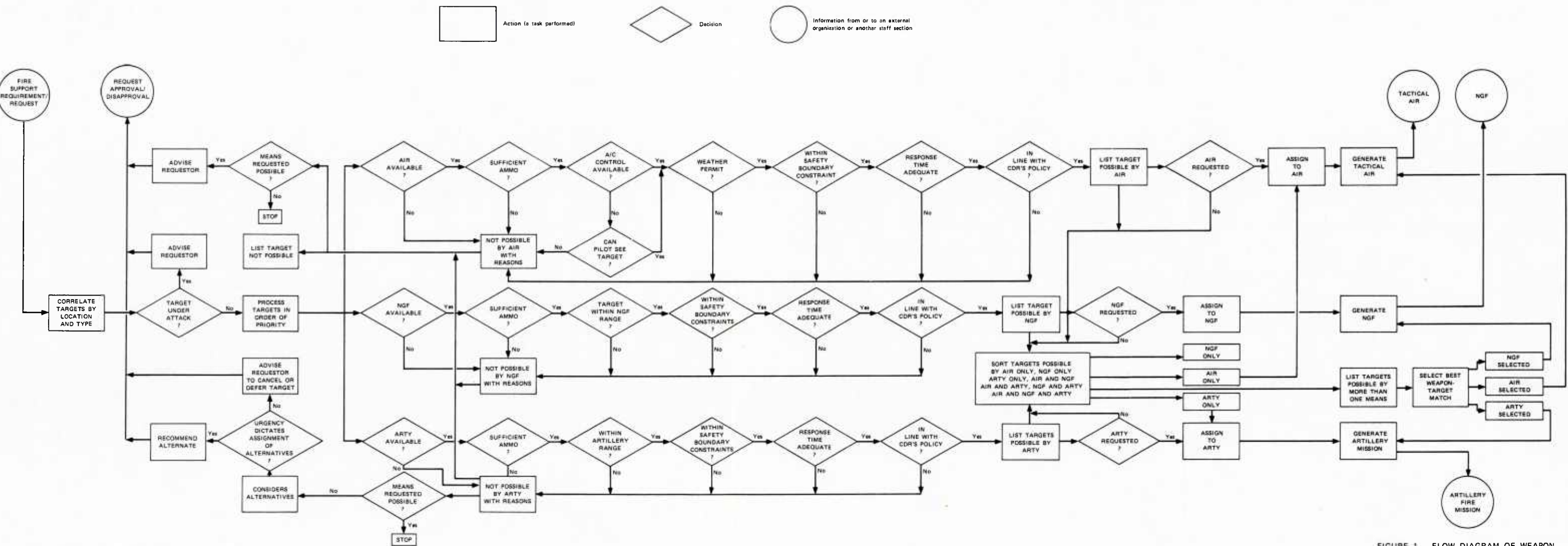
The sequence of events in the process of selecting the supporting arm weapon system is illustrated in the flow diagram in Figure 1.

Table 5

CRITERIA FOR USE OF NAVAL GUNFIRE AND/OR OFFENSIVE AIR FIRE SUPPORT

Criteria	Explanation	Application to	
		NGF	OAFS
Sole capability	Other supporting arms (SPA) lacking capability to accomplish desired result (Note - although identified as one of nine criteria, this is a general criterion covering most of remainder)	X	X
Range exclusion	Target out of effective range of other SPA	X	X
Terrain mask exclusion	Target is terrain masked for other SPA fires	--	X
Enfilade fire exclusion	Enfilade fires are needed and not available in other SPA	X	X
Target destruction efficiency	Target construction permits destruction more effectively or economically	X	X
Large area neutralization	Nature of target is large area requiring neutralization for limited time	--	X
Napalm exclusion	Napalm use is desirable to attack target	--	X
Rapid target retrogradation	Target is moving rapidly away from friendly forces	--	X
All-out exigency	Urgent situation requires use of all available SPA	X	X

Source: FMFM 7-1, p. 39, and FMFM 6-2, p. 112.



SOURCE: A. Blen, "Marine Tactical Command and Control Study (MTACCS)," Vol. V, Appendix D:
 "Fire Support," Final Report, Stanford Research Institute, Menlo Park, California (September 1966).

FIGURE 1 FLOW DIAGRAM OF WEAPON
 SELECTION PROCESS SEQUENCE

IV FUTURE TRENDS AND INFLUENCES

Fire support mix analysis methodology is of principal interest and application in dealing with decisions involving weapons and supporting systems in the future. It therefore behooves the methodology designer and his critic to take into account the likely nature of future operations, the operational environment in which they are projected, and the technological trends that may affect future systems. The methodology should be designed to meet the future fire support needs. Of particular interest is the adequacy of the methodology for use in the distant time frames where the span of technological opportunities are greatest.

This subsection is designed to bring out in summary form the trends and influences foreseen for future operations that may impact significantly on the methodology needed for evaluating relevant fire support mixes. The groupings found below are intended to facilitate correlation with the methodological process groupings developed subsequently in this part. The evaluation of the impact on methodology is developed in Part III.

In dealing with future supporting arms systems* the Marine Corps has broken down the time frames into the following three categories:

- (1) Late midrange period--7 to 10 years in the future
- (2) Early long range period--10 to 14 years in the future
- (3) Late long range period--15 to 20 years in the future.

The description of future trends and influences is derived from Marine Corps sources. They are stated largely in general terms of an

* GOR, SPA-1.

unclassified nature, since this degree of definition is sufficient for use in the Guide. Generally speaking, it is the fact of a change rather than the magnitude of the change that is of interest in the Guide. The numerical quantities become important when they are to be injected as input values into a particular evaluation.

A. Operational Environment

Future trends and references that are expected to affect operational environments are:

- (1) The traditional Marine Corps force-in-readiness role within the amphibious assault environment along the world's littoral areas is expected to continue.
- (2) Emphasis is increasing on sea basing of forces with flexibility to shift easily to land basing and vice versa.
- (3) Basic organization of landing forces is expected to continue as varying-sized air-ground task forces (MAU, MAB, MAF), with a trend toward greater amalgamation of air and ground units.
- (4) Distance over which landing forces may be projected from ship to shore and inland from shore are expected to increase by a factor of 3 to 4 or more over present operations.
- (5) Most conflict involvements are likely to be of low and mid-intensity, but higher levels, including nuclear warfare, are not to be ignored.
- (6) Urban areas are expected to become increasingly important as a combat environment.
- (7) Physical environmental conditions to be met are expected to continue to cover full range with somewhat decreased prospects for arctic operations.

B. Threat Characteristics

Future trends and influences that are expected to affect characteristics of the threat are:

- (1) Marine forces must anticipate meeting a wide spectrum of enemy weapons ranging from unsophisticated and obsolete systems at the low intensity conflict level to the most sophisticated and advanced systems at the high intensity level. The possibility exists that Marine forces may face some of the latter weapons at the medium intensity level when it suits the donor country to provide advanced systems to less-developed countries.
- (2) The tridimensional nature of the hostile land combat threat is increasing.

C. Infantry Combat Systems (To Be Supported)

Future trends and influences that are expected to affect infantry combat systems are:

- (1) Major increase in combat effectiveness of infantry combat systems is expected to be sought through:^{*}
 - Greater ability to sense the total operating environment
 - Improved firepower employment capability and resources
 - Improved command and control by more efficient execution of the sense-evaluate-decide-act process.
- (2) The tridimensional nature of infantry land combat is expected to increase with the possibility of TAORs at battalion and higher level becoming three-dimensional TSORs (tactical space of responsibility) that cover areas five times or more than present day areas and include an altitude ceiling.
- (3) Tactics of ground maneuver elements (i.e., principally infantry) will evolve to those of a search and attack concept that emphasizes employment of firepower at standoff ranges to defeat the enemy rather than close combat fire and maneuver.

^{*} Brig. Gen. F. P. Henderson, USMC (Ret.), "The FMF: An Alternative Future and How to Get There," in "Marine Corps Gazette," July 1970.

D. Supporting Arms Weapons (As Part of Firepower System)

Future trends and influences that are expected to affect supporting arms weapons are:

- (1) Volume of supporting fires required for preassault and assault operations may be lessened because of improvements in position location, target acquisition, and terminal delivery accuracy.
- (2) Effectiveness of all supporting arms is expected to improve significantly in terms of response time and precision fire.
- (3) Increased firepower delivery capability should require comparatively fewer personnel, weapons, and support equipment.
- (4) Reliability, maintainability, and modularity in future weapon systems are expected to have increased emphasis.
- (5) Range capabilities of artillery and naval gunfire weapons may increase as much as twofold and tenfold, respectively. In the case of air support, conventional takeoff and landing (CTOL) aircraft radius will continue on the order of 500 to 600 nmi, V/STOL aircraft radius may increase to the same order, and ASM standoff ranges may increase to 50 to 60 nmi.
- (6) Use of naval gunfire and air support is expected to increase because of the increased ranges of naval gunfire weapons, and the improved delivery accuracy, all-weather target acquisition capability, and responsiveness of attack aircraft, including armed helicopters.

E. Other Functional Areas

Other functional areas that are expected to be affected by future trends and influences are discussed briefly below.

1. Intelligence

Target acquisition capabilities are expected to increase significantly, especially at long range, because of vastly improved means--

search and attack teams in the infantry, versatile air reconnaissance vehicles, and the high resolution of sensors and rapid processing of information attainable under all-weather conditions.

2. Command, Control, and Communications

There are three projections for command, control, and communications:

- (1) Complete compatibility of Marine Corps and Navy tactical command, control, and communications systems is to be sought, plus interface-commonality in equipment and support training with the other Services.
- (2) Fire support command, control, and coordination systems, as developed in the MIFASS system of the MTACCS concept, should provide increased efficiency in response times and weapon allocations.
- (3) An automated logistic support command and control system afloat is expected to enable more responsive and efficient support, with consequent reduction in logistic burden of supporting arms units ashore.

3. Mobility

Tactical movements of infantry and supporting artillery are expected to be accomplished increasingly, in both volume and distance, by V/STOL aircraft.

4. Logistics

Sea-basing emphasis is expected to cause increased use of ships for logistic support of supporting arms ashore, including ammunition supply and maintenance.

V KEY ELEMENTS FOR SYSTEMS ANALYSIS

A. Fire Support As a System

1. Constituent Parts of Fire Support

One method of separating fire support into its constituent parts is to identify the functions resulting from the interaction of the fire support system with the enemy target arrays.

First, an overall surveillance function peripheral to fire support is performed to sense the presence of the opposing force target array.

Next, the target acquisition function refines this broad surveillance information in terms of detection, identification, and location of specific targets in sufficient detail to permit the effective employment of weapons. Also included for our current purposes are the decisions about which targets require fire support and the priority order in which these targets should be addressed (i.e., target analysis). The output of the target acquisition function is therefore a target list that includes the target identification, location, effect desired, and the fire support weapon preference.

Next, the target allocation function matches the specific type weapon (including ordnance and ordnance configuration) with the target within its environment. This function accounts for the weapons, their current and projected availability status, the availability of logistics, and other factors that could affect the allocation and expenditure of fire support resources.

The weapon delivery function includes all necessary operations of the weapon systems. This includes all preparation of the fire delivery means and necessary ordnance, coordination, execution of the fire mission, and return of the weapon system to a state of readiness.

The damage assessment function is initiated with the delivery of ordnance on the target. The assessment of the results is a function that is necessary to indicate when the desired effects have been achieved, to determine changes in the target status, and to update the changes in the target acquisition information. This assessment provides the essential feedback to improve both the estimates made about fire support weapon system requirements and the detailed state of knowledge about the target array resulting from the application of the supporting firepower.

The last function is fire support scene evaluation. The effects of the application of the fire support can be assessed for revisions of the opposing force target array in terms of composition and disposition. This assessment serves to update the target acquisition and overall surveillance information that, in turn, impacts on planning for the conduct of friendly operations.

Figure 2 depicts these elements arranged in a way to achieve such a system description of fire support.

It should be noted that the input and output of the system are the opposing force target arrays. The differentiation into prior and posttarget arrays signifies that the primary objective of fire support is to achieve a modification of the enemy target array. Any measure of the effectiveness of a fire support system must represent the capability of a candidate system to make such modifications. This implies a change in target array with time. More specifically, the application of fire support serves to modify an enemy target where the desired modifications are specified in terms of desired effects and a schedule for their accomplishment.

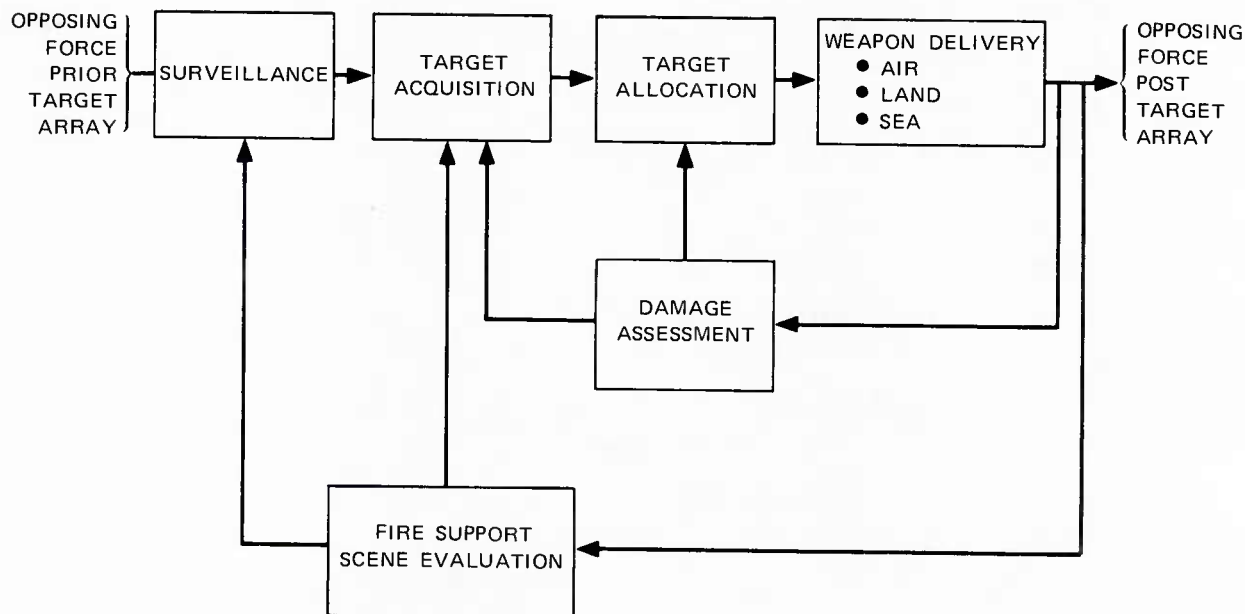


FIGURE 2 CONCEPTUAL FIRE SUPPORT SYSTEM

The feedback through the damage assessment and fire support scene evaluation functions could represent the major capability in reducing errors that frequently exist in target identification and location.

2. Fire Support Mix Methodology Elements

The preceding describes fire support conceptually in system terms and establishes that the primary objective of the fire support system is to achieve desirable modifications of the hostile target array. In analyzing fire support systems, however, it is necessary to generate

the opposing force target array and a friendly force fire support system, including not only the weapons themselves but the means by which targets are acquired, the doctrine and organization for employment, the logistic chain, and the command and control mechanism.

Figure 3 identifies the interrelationships of the key elements of a fire support mix methodology. Outlined in the center in heavy boxes are five methodological functions that must be performed:

- Fire Mission Generation (What is the fire support system to be used for?).
- Fire Mission Allocation (How are the available fire support means to be paired with targets?).
- Fire Support System Effectiveness Determination (How is effectiveness to be measured?).
- Fire Support System Mix Selection (What criterion(a) is (are) to be used to choose the recommended mix?).
- Fire Support System Cost Analysis (What are the appropriate costs associated with the fire support system?).

Also shown in a row at the top of the figure are key inputs and at the bottom the functional areas of Intelligence, Command and Control, Mobility, and Logistics. The relationship of inputs and functional areas to the functions to be performed is depicted. Each element will be described in more detail in the succeeding subsections.

B. Fire Mission Generation

Fire mission generation is a key element in any fire support methodology since it drives the entire process. Fire support exists to bring the effects of fire to bear to allow the accomplishment of the commander's mission. As expressed earlier, this can be stated as the ability to make desirable changes in the hostile target array. Credible targets and missions for fire support must be generated to represent the demand placed on the fire support system. Based on this demand, individual

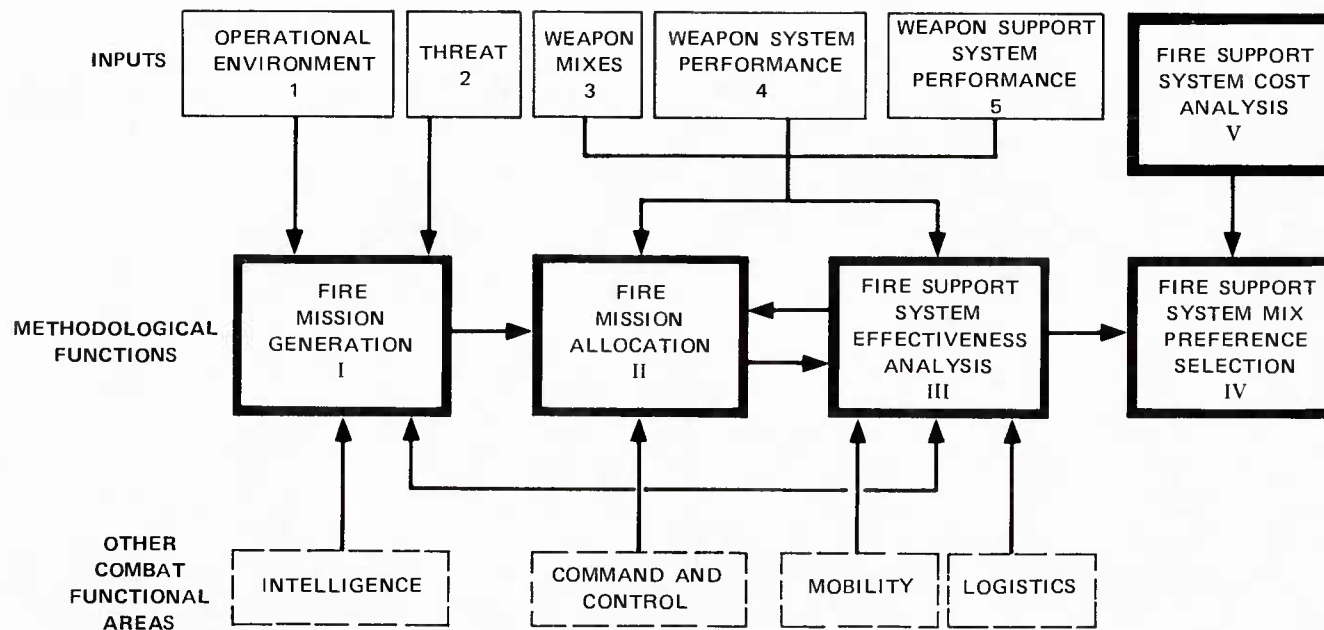


FIGURE 3 INTERRELATIONSHIPS OF KEY ELEMENTS OF FIRE SUPPORT METHODOLOGY

weapon systems can be selected by type and quantity to form an overall fire support capability or, alternatively, preselected systems can be tested against it. The missions (or requirements for fire support) must reflect the operational environment and the threat posed by the enemy forces.

1. Operational Environment

The operational environment is an input factor to any fire support study. Possible operational environments cover a wide spectrum of conflict situations, geographical locales, friendly missions, operational concepts, and force levels. Because of this variety the sensitivity of study results to differing operational environments should be tested by a series or spectrum of environments covering the range of interest.

2. Threat

The threat describes the opposition. Order of battle information, general characteristics of the hostile force, the disposition of the enemy's available forces, and the tactical doctrine he follows are all important. The threat and the operational environment together generate the array of opposing forces.

3. Fire Mission Generation Subelements

- a. Actual Target Array

Predicated on the operational environment and the threat, a specific or finite array of hostile forces must be generated. Different techniques to generate these target arrays will be discussed in Part II. The actual target array describes the enemy targets in terms of type, size, location, and activity as they truly exist. It should

be dynamic and should change as the battle progresses. For purposes of fire support analysis, this target array is ground truth, i.e., it represents exactly where the enemy is and what he is doing. This is in contrast to the acquired target array (to be described presently) that represents friendly force knowledge and assessment of hostile targets.

b. Target Acquisition

This element is used to encompass all the target-acquiring systems of the friendly forces. It comprises surveillance, reconnaissance, and target acquisition means, including electronic intelligence devices. These systems act on the target array and produce the material for the mission list. The friendly forces will not know the exact location and description of each hostile target. The system used to acquire targets will not only miss some targets completely, mislocate or misdescribe others, but undoubtedly will introduce spurious ones. Some target acquisition system attributes of interest are the ability to determine the effect of fire on hostile targets, the time delays associated with reporting information to an activity with the capability to act upon it, and its continuous and dynamic nature.

c. Target/Mission List

The result of the target acquisition system acting on the actual target array is the picture of the enemy force as Blue sees it, in effect, the acquired target array. Blue places these targets, after analysis for their possible impact on his scheme of maneuver and mission, into a priority listing. This list is designated a target/mission list. The word "mission" is included in this term because the list contains fire missions such as illumination, harrassment, and interdiction, as well as destruction and neutralization. Also, based on the target description, location, and effect desired, a supporting arms preference

is indicated.* This list now forms the demand for the use of fire support systems.

C. Fire Mission Allocation

When the requirement or demand for fire support has been established, resources must be allocated to satisfy the demand. The various missions must be assigned to the fire support weapons available to the friendly force commander. This generally is a two-step process. First, the mission is assigned to a supporting arm, and then a further allocation is made within that supporting arm to a specific weapon. Necessary inputs to this allocation process are the weapons available (i.e., weapon mix), the weapon system's performance characteristics, and the weapon support system's performance characteristics.

1. Weapon Mix Generation

The types and numbers of weapons to be considered must be stipulated to pair up missions with weapons. The generation of mixes to be analyzed can be either quite elaborate, based on military experts' study of the missions previously generated and selection of mixes appropriate in their judgment to handle those requirements, or quite simple, such as a mix of current and/or programmed weapons. The important point is that the quantity and type of weapons must be available to start the allocation process. Further, it is necessary to establish a firing doctrine and assign tactical missions to the various weapons that are in consonance with the operational environment factors. All sources of fire

* It should be noted that neutralization of some targets may be achieved without placing fire upon them. For example, some targets may be neutralized and thus prevented from accomplishing their objective, by employing ECM. In this use ECM may be considered as a weapon substitute, and certainly its use should be integrated with conventional fire support means.

support should be included, such as air, artillery, naval gunfire, and armored combat systems. Electronic warfare systems should be included also because they can be used to satisfy certain requirements (ECM) on the mission list.

2. Weapon System Performance

These are the performance characteristics of the individual weapon systems under consideration. There are well-known characteristics of the major supporting arms, such as the flat trajectory and high muzzle velocity of naval guns, the massing capability of artillery, and the speed and maneuverability of aircraft. The finite performance characteristics and capabilities of the weapon and its ordnance in the manner employed, however, must be available.

3. Weapon Support System Performance

Similarly, the performance characteristics of the support system must be known. For example, such factors as ordnance availability, resupply rate, rearming and refueling time affect the ability of the weapon systems to produce and sustain fire.

4. The Allocation Function

The allocation function addresses the manner in which missions are actually assigned to weapons. Factors involved in this process relate to the target, such as type, location, priority, and duration; to the supporting arm, such as capability, availability, and responsiveness; and to constraints, such as logistic supportability, safety of friendly troops, desire for surprise, obstacle creation, and civilian casualties.

D. Fire Support System Effectiveness Analysis

Once a mission has been allocated to a fire support means, the next function to be performed entails the analysis of how effectively the assigned mission is accomplished. The analysis concerns the performance of the weapon system and the weapon support system and is affected by the accuracy of the target location and identification information. There are two types of measures of effectiveness (MOEs) applicable to fire support: quantitative and qualitative.

1. Quantitative Measures of Effectiveness

Quantitative MOEs are measures that can be quantified, such as targets killed in a given time, friendly force casualties, and cost to perform the assigned missions. A distinction must be made between a measure of effectiveness and a measure of performance. For example, one weapon may fire more rapidly than another (a measure of performance), but effectiveness must be related to an effect on the hostile array or the accomplishment of the friendly mission. In other words, it must be not only quantifiable but also relevant to the determination of the fire support mix.

2. Qualitative Measures of Effectiveness

There are measures relevant to the effectiveness of fire support means that often cannot be adequately quantified; for example, how such attributes as mobility, flexibility, and complexity contribute to fire support effectiveness. The fact that these and similar measures are difficult to quantify does not mean that they should not be considered in the final mix preference selection process. They should be considered qualitatively if not quantitatively.

E. Fire Support System Cost Analysis

An essential element in the determination of a mix of fire support systems is the analysis of the cost of the resources involved. Because quite disparate systems are necessary to provide fire support (i.e., ground, sea, and air systems, which operate in different environments and differ as to whether fire support may be the sole reason for their existence), it is particularly important that a consistent, overt method of costing be used and that the method of allocating costs to multimission systems be credible. In days of great emphasis on achieving the maximum use of resources, the cost of resources used in providing fire support must be considered in selecting among alternative weapons systems.

F. Fire Support System Mix Preference Selection

The final function to be performed is the selection and exposition of a mix preference as a basis for ultimate decision on the fire support mix desired.

Key ingredients to the mix preference are the results of the effectiveness analysis and the cost analysis. These must be related in some way to show how the costs vary with effectiveness. A criterion or criteria must be established to enable selection among alternative systems. The most common method is to select a fixed level of effectiveness and determine which system can provide that level of effectiveness at least cost or, alternatively, to establish a fixed cost (budget) and determine which system provides the greatest level of effectiveness for that budget. This part of the analysis is predicated on quantification. The final preference selection should include consideration of the nonquantifiable (or qualitative) factors as well.

VI FIRE SUPPORT SYSTEM PARAMETERS

The key elements of a fire support mix methodology are depicted in Figure 3 and described and discussed in the preceding section. These key elements are further dissected in Appendix A by examining the inputs and methodological functions. This is done to determine the subelements and input factors or parameters that should be considered in the actual execution of a fire support mix study.

When this examination was completed, it was found to be inappropriate to reduce the large array of parameters to a smaller list without knowledge of the reasons for which a particular fire support study was being conducted. Certain system performance parameters, such as responsiveness, accuracy, lethality, range, and reliability, undoubtedly play a key role in any fire support study, but they are representative of only one element of an entire fire support methodology.

The extensive detail contained in the listings in Appendix A is not needed for the remainder of the analysis of fire support techniques. It is provided, however, because of its possible value to an analyst in the actual conduct of a mix study.

VII INTERRELATIONSHIPS OF FUNCTIONAL AREAS

The Marine Corps has divided combat into five^{*} functional areas for planning: firepower; intelligence; command, control, and communications; mobility; and logistics.

There is no agreed on analytical expression for the impact of the various functional areas on the outcome of combat. However, there is substantial agreement that each contributes significantly to the successful outcome of battle and that there are trade-offs to be made among the functional areas. For example, casualties are one indicator of how a battle is progressing. It has been pointed out that some games attempt to compute casualties directly from weapon performance characteristics without taking explicit account of synergistic weapon effects; command, control, and communications; or battlefield mobility. Frequently, logistic functions are ignored as well.

Although quantitative relationships are noticeable by their absence, there is a good qualitative appreciation of these functional interrelationships. This appreciation is based on historical experience but, as the basic character of combat (new weapons, organization, and tactics) change over time, the World War II, Korean, and Vietnam experiences become less relevant.

Fire support, as stated previously, is a part of firepower. Figure 4 indicates graphically how the functional areas interact with firepower.

*There is a sixth--manpower--that is not addressed separately here but whose impact is felt within each of the other functional areas.

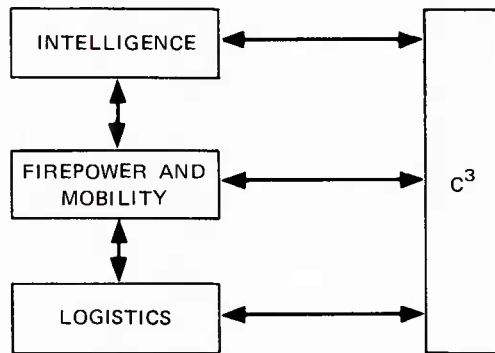


FIGURE 4 INTERRELATIONSHIPS OF COMBAT FUNCTIONAL AREAS

A. Intelligence

The first methodological function in Figure 3 was Fire Mission Generation. The combat functional area of intelligence provides the initial indication of the existence of targets for fire support weapons to be used against. It provides the number and type of targets that drive both the allocation and effectiveness analysis functions. Firepower calculations are affected by the accuracy of intelligence, e.g., target densities. Of even greater import is the fact that intelligence affects the commander's entire operation plan, including the scheme of maneuver and resultant fire support plan.

The accuracy of intelligence information is important in that false information, if believed to be correct, causes inefficient use of fire support means. Target acquisition affects the range of engagement, intensity of combat, ammunition consumption, and casualty rates. Intelligence interacts with command and control in providing both the initial reason for use of fire support and, after its use, the enemy reaction to that action. The intelligence function also can influence effectiveness calculations by ensuring that there are or are not sufficient targets to

use weapons to their performance capacity. The area coverage of intelligence systems affects the size of the area over which fire support systems can provide support.

B. Logistics

The logistics function impacts on fire support in a direct way. The tempo and length of operations are based on the availability of logistic support. If ordnance becomes unavailable, fire support ceases completely. In times of ordnance shortages, ammunition expenditure is reduced. Over the long run no more ammunition can be expended than the logistic system provides. Logistics, therefore, impacts directly on fire mission allocation and fire support effectiveness and indirectly on fire mission generation.

There are trade-offs to be made with respect to weapon characteristics and the amount of logistic support. For example, if weapon systems have increased accuracy and lethality, less ordnance should be required for the same level of destruction, and the result will be decreased logistic costs.

The logistic function is directly represented by the Weapon Support System Performance inputs. Reduced time for weapon systems to be out of action for repair and/or maintenance reflects in increased availability, which affects mission allocation and system effectiveness.

C. Command, Control, and Communications

As shown in Figure 4 the command, control, and communications functional area interacts with each of the other functional areas. Intelligence is of no great value until it is made known to the decision-maker, who then must, in the case of targets, pass them to a fire support means. The existence of a target does not necessarily mean that fire is to be brought

to bear. The commander generally has the option of fire and/or maneuver. If the decision is made to use fire support means, the command, control, and communications system directly affects the rapidity with which fire resources can be allocated and employed. In addition, the ability to locate accurately and report immediately friendly and enemy positions affects the effectiveness of the fire support system.

D. Mobility

Mobility has been shown intimately related to firepower in Figure 4 because mobility of forces affects the need for and the availability of firepower, and vice versa. Fire support and mobility have many areas of trade-off; for example, weapons with long effective range do not require as frequent movement or as great mobility as weapons with short effective ranges.

Part II

ASSESSMENT OF FIRE SUPPORT METHODOLOGIES

I INTRODUCTION

Part II of the Guide describes methodologies available for analyzing the fire support system. It identifies the strong and weak points of existing methodologies and suggests alternative approaches where appropriate. Its purpose is to provide the analyst studying fire support with an understanding of how others have attacked problems similar to his, to alert him to what the essential elements of the methodologies are, and to provide insight into which elements are the most difficult to handle and thus require early attention during the formulation of the methodology for a particular study.

Some of the alternative approaches and techniques presented are untried and therefore are presented only as suggestions deserving consideration. They are proposed either as candidates to fill voids in existing methodologies or simply as alternatives that may be more appropriate than techniques used in the past. Furthermore, because the fire support system of the future promises both new concepts of operation and new systems, innovative techniques may be needed to assess their impact on fire support requirements.

It is believed that, in general, the same key elements (Figure 3) are applicable to fire support mix studies irrespective of time frame. The major differences between midrange and long range fire support studies lie in the availability and quality of input data. It is very difficult to gather acceptable data, especially for the long range. In this regard long range studies may require the application of additional analytical tools to derive the input data in the face of the greater uncertainties. Additionally, sensitivity analyses for uncertain, tenuous, or unavailable

data in the longer time frames are a requisite for displaying the possible variation in results as a consequence of the range of input values. Also, because of the great difference in depth of detail available between the time frames and the greater uncertainty as the time horizon is extended, less specific objectives would be expected in long range studies. Attempts to resolve the fire support mixes in the depth described in this Guide are most applicable to the midrange but such depth would not be expected for the long range.

The many facets of the fire support system demand a comprehensive methodology for the selection of preferred mixes. The most practical way of providing such a methodology is through a hierarchy of models, as pictured in Figure 5. Three levels are shown. At Level I is the Fire Support System Aggregated Model (FSSAM) (not an existing model). FSSAM serves two purposes: it provides a check on the lower level models and facilitates sensitivity analysis. It checks the lower level models by testing the impact of assumptions made in their formulation. Typically, many of the effects of intelligence, command and control, logistics, and mobility are ignored in the lower level, higher resolution models. FSSAM provides the mechanism for measuring the reaction of the overall system to such assumptions in an aggregated way.

Most models like those pictured below FSSAM in Levels II and III are cumbersome and expensive to operate; consequently, they are seldom used for sensitivity analyses. But sensitivity analyses should be an important part of the fire support system evaluation methodology. FSSAM allows sensitivity analyses based on input from higher resolution models, and allows the analyst to interpolate and extrapolate quickly many results from the few results provided by the models below it in Figure 5.

Level II of the model hierarchy shown in Figure 5 is the "key element" level. Here models are defined in terms of four key elements of fire

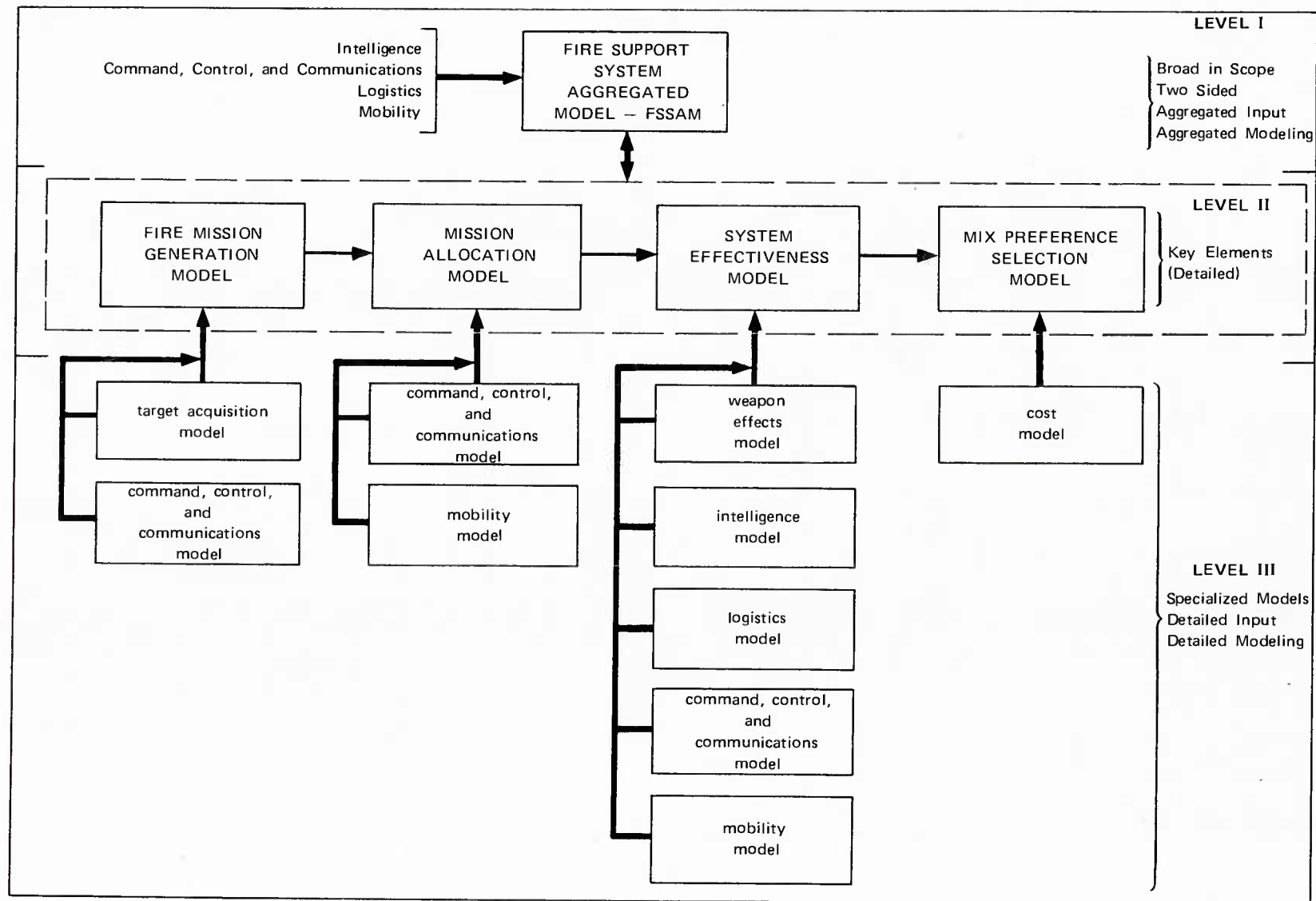


FIGURE 5 HIERARCHY OF MODELS/PROCEDURES FOR FIRE SUPPORT MIX STUDIES

support as defined in Part I, Section E. The models and procedures associated with these elements comprise the major portion and heart of the hierarchy of models. It is at this level that the fire support issues are addressed. Mix selection, coordination of supporting arms, and target selection are some of the issues that receive special attention here.

In all the studies reviewed that truly address the fire support mix problem, at least some of the modeling of the four key elements has been done independently;* that is, fire mission generation is finished for all missions before any mission allocation takes place, and allocation is completed before the effectiveness determination for any systems begins, and so on. For this reason most of this section is devoted to independent discussions of current and alternate techniques for each of the four key elements. However, as will be brought out later in the analysis of strength and weakness of existing methodologies, many of the most troublesome problems with fire support mix studies stem from this compartmentalized approach. For this reason this report also discusses the possibility of a more unified approach.

Level III of the model represents the highest resolution. These models are parts of independent side analyses that address specific parts of the problem in great detail. Their output is tailored to the input needs of the key element models. For the most part the models at this level exist. In fact, in some cases, the output needed from them may already exist. For example, much of the weapons effects data for existing weapon systems is available in the form needed by the Weapon Effectiveness Element.

* Some of the studies do not treat all four key elements. However, the Naval Weapons Laboratory, Dahlgren, study,¹ which has the most comprehensive fire support methodology available today for amphibious operations, models all four elements and does so as independent entities.

Section II of this Part describes in general terms the approaches taken to fire support mix evaluation and related problems by the studies reviewed for this report. (Detailed descriptions of those studies are available in Appendix C.) It also presents an alternative approach to the solution of the fundamental fire support problem, i.e., the selection of a preferred mix(es) of air, artillery, and naval gun systems.

Sections III, IV, and V present descriptions and evaluations of the techniques used in the reviewed studies in the key element areas of Fire Mission Generation, Mission Allocation and Weapon Effectiveness, and Mix Selection, respectively. Section VI discusses cost analysis. Each section also presents alternative techniques as deemed appropriate.

II THE OVERALL APPROACH

A. Techniques in Use

The studies reviewed display a wide variety of methods of approach and study scope. Some cover comprehensive methodologies embracing the entire fire support system; others are fairly simple studies that consider only small parts of the system. Some studies have broad objectives; others, narrow ones. Some are USMC studies; some, Navy; and some, Army. A few have methodologies that can be applied to fire support problems and are useable and should be exploited. Because of this diversity, the studies are difficult to compare. They are reviewed here to determine how their methodologies might contribute to the solution of the basic fire support problem, i.e., selecting an "optimum" mix.

The following are synopses of the overall approaches used by the studies reviewed. Summary analyses of these selected fire support studies are contained in Appendix C.

1. Center for Naval Analyses (CNA) Study²

The CNA methodology is simple. Target lists were developed by inspection of two scenarios from the period D-Day to early on D+1. The target list was input to a computer simulation that played various fire support forces against the targets. Simulation results were then compared to determine the relative cost and effectiveness of alternative approaches to increasing the fire support capabilities of the fleet. The major constraint on the scope of the study is the assumption that tactical air, Marine artillery, and destroyer force levels and compositions are determined on the basis of broader considerations than the requirement for

fire support during the amphibious assault. This means that there are no trade-offs among air, artillery, and naval guns. The study is not a mix study; it considers only naval gunfire in detail.

2. Lockheed Dynamic Effectiveness Model Study (DEMS)³

This study was not a mix study per se, but a model development effort. The model, DEMS, is designed to simulate the fire support system, given a mission list. It does not attempt to select an optimum mix.

DEMS simulates the combat of two forces in several phases, using a preconceived concept of military operations. Combat dynamics of the forces are based on a series of localized actions called "Delta Battles." Blue fire support operations and Red counterfire operations are conducted using a specified plan of support. Direct fire is handled with a maneuver force fire fight model.

The basic concept of the model is as follows. A campaign is described for a given physical and tactical environment. The campaign description is given first in terms of tactical phase lines that determine force positions at particular milestones in the campaign. Within each phase is a set of independent Delta Battles. Each Delta Battle comprises the subintervals of approach, preparation, closure, assault, and reorganization and movement.

The entire campaign is developed incrementally by Delta Battles and by campaign phases as a manual two-way map exercise. A targeting plan is developed. The computer model calculates the outcome of the Delta Battles by proceeding through the subintervals listed above.

Output is available on a battle-by-battle and phase-by-phase basis. The output provides the timing of each battle, the casualties to both sides, and the resources expended (both ground and air).

3. Lockheed/USMC Study⁴

The study begins with the definition of a mission list based on historical data and military judgment. Although the study does allow for a comparison of various mixes of air, artillery, and naval gunfire weapon systems, its primary objective was to evaluate different land weapon system design characteristics. Consequently, there was a limited choice of mixes under consideration, particularly with respect to air and naval gunfire.

The next step is the definition of weapon systems characteristics in terms of range, accuracy, lethality, strength, tactical location, and three-hour delivery capability. The analysis progresses in three-hour battle increments to take into account real-time factors pertinent to the mix evaluation and yet not make the analysis prohibitively complex.

Mission requirements per time period are generated from previous studies and conferences and are provided in the form of target numbers consistent with acquisition rates and accuracies, target sizes, hardness, locations, and priorities. For each target type, a criterion for minimum acceptable coverage and damage is established.

Each weapon system and its ordnance capabilities against each type of target are ranked in a weapon selection priority table according to its relative on-target effectiveness, its relative system response time, and its overall supply availability. These three are all inputs to a simulation model used to evaluate various weapon systems characteristics and various fire support mixes. Outputs of the simulation model are then combined with cost information and other factors for system/mix comparison.

4. USMC Fire Support Requirements Study⁵

The study initially defines its dimensions in order to set limits on the study effort and ensure that the study is directed toward results that are realistic and responsive to the needs of the Marine Corps. A limited war rationale is discussed, enemy threats in two geographical areas are defined, and an MEF to counter the threats is developed. Fire support requirements are arrived at by considering the study dimensions; MEF fire support organizations, functions, and tasks; command, control, and coordination of fire support; target acquisition, reconnaissance, and surveillance capabilities; and the tactical employment of MEF fire support systems.

Weapon systems expected to be available during the 1965-70 time frame are selected and evaluated; a Weapons Systems Evaluation Model provides quantitative data; selected weapon system mixes are analyzed by a computer analysis and a hand-computation analysis; and recommended weapon systems are selected. The computer analysis uses the Lockheed model developed in the "Lockheed/USMC" study with some modifications.

The methodology used in the study is very pertinent to the Guide since it does encompass a comprehensive fire support mix methodology and includes the use of the Lockheed computer model. However, it is primarily an artillery mix study with air and naval gunfire treated as less than full range variables. There is a more recent, updated effort by NWL for the determination of Navy and Marine Corps fire support requirements, which is reported on in Appendix C and is discussed extensively in this Guide. The computer model was developed further by Lockheed and the latest version is described in this study under the title "Lockheed/DEMS." The areas of difference between the original Lockheed computer model and the subsequent version used in the subject study are described in Appendix C in the summary analysis. Thus, it is

considered that adequate treatment is given elsewhere in the Guide to the methodology found in the USMC Fire Support Requirements Study and accordingly no further reference is made to it in this volume.

5. Naval Weapons Laboratory System^{1*}

The NWL, Dahlgren, study uses a comprehensive methodology. Mission lists were developed from a series of four war games. Candidate mixes were selected by reviewing each target in the lists and ranking the supporting arms by preference for the target. The set of candidate mixes of air, naval gunfire, and artillery were evaluated against the mission list in a simulation. The results were used with regression techniques to develop a surface of effectiveness as a function of mix composition. This surface was used to conduct a fixed effectiveness, minimum cost analysis directed toward the selection of an "optimum" weapons mix. The selection process was conducted primarily by a nonlinear programming technique. A detailed cost model was developed and implemented to predict the cost of the diverse weapon systems comprising fire support.

6. Ohio State University Study--DYNTACS⁶

This study, actually entitled "The Tank Weapon System" but frequently referred to simply as "DYNTACS," comprised the development of a series of models. The Design Models were developed to predict individual weapon system performance of certain combat functions. These models are in the general areas of mobility, detection, firepower, and protection. Within these areas, submodels were used to predict performance as a function of various terrain and environmental variables. The

* In addition to the MAF Fire Support Study, the MAB Fire Support Study is also addressed in Appendix C.

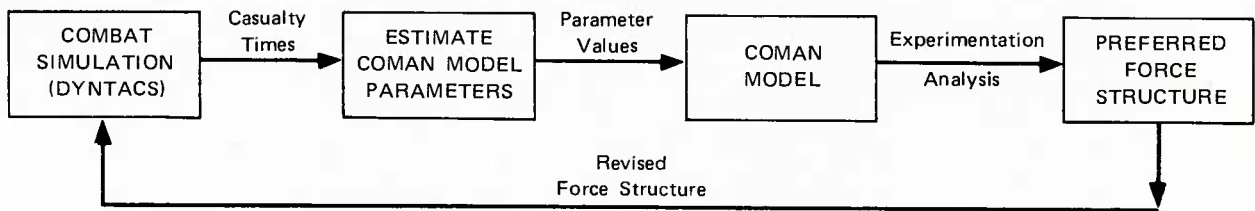
effect of unit organization and tactical variables on combat performance is also considered.

The principal Operations Model is a high resolution simulation, called "DYNTACS," of combat engagements varying in size from a single weapon to a battalion. The results of the Design Models are used to simulate a dynamic battle environment where both forces can be mobile at the same time. It is dynamic in the sense that the mechanics of the battle are not prescheduled. The combat units within the model are constantly evaluating the battle situation to pick the tactic most appropriate for the tactical doctrine expressed by the input data. It is an event-sequencing simulation that uses Monte Carlo techniques to handle uncertainties such as those associated with detection and kill of targets.

Because it would be cumbersome and costly to use DYNTACS to study the behavior of a large unit like a battalion in a sustained combat action, the study developed a large unit, sustained action, analytical model called "COMAN" (Combat Analysis Model).

COMAN consists of mathematical expressions that predict attrition as a function of the initial force sizes of two opposing forces. The data generated by DYNTACS are used to estimate the input parameters of weapon kill rates and target acquisition probabilities.

An important application of the COMAN model would be to identify a preferred battalion force structure from the viewpoint of battalion-sized operations. Using the results of DYNTACS, COMAN can extrapolate these results to evaluate alternative weapon mixes and identify a preferred force structure. The procedure can be summarized as follows:



The feedback loop indicates that, once a preferred force structure is indicated, it is checked by running it through DYNTACS. By alternately using DYNTACS and COMAN, the preferred force structure can be found.

COMAN is a stochastic model that is an extension to the Lanchester type combat models. It allows for a more comprehensive representation of intermediate conditions concerning target acquisition as opposed to a strict application of the Lanchester square and linear laws.* Additional extensions include allowing for heterogeneous forces with a variety of weapon types and allowing for variations in firepower effectiveness and target acquisition capabilities as the battle progresses and distances between opposing forces change.

7. University of Michigan Study⁷

Michigan's study is also a model development program and not a mix study. It is not as directly applicable to the fire support system as the Ohio State work, but it is presented here because it provides a potential basis from which the aggregated fire support system model can be developed. Michigan has done considerable work in making the Lanchester theory useful for detailed combat analysis.

* In the Lanchester laws, either all the enemy target positions are assumed to be acquired and consequently able to receive concentrated fire, or none are.

The basic concept of the methodology is Lanchester's differential approach. Mathematically, if

n_j = the number of surviving Red units of the j th group
($j = 1$ to J)

m_i = the number of surviving Blue units of the i th type,
($i = 1$ to I),

then the Lanchester equations are in the form of coupled sets of differential equations:

$$\frac{dn_j}{dt} = -\sum_{i=1}^I A_{ij}(r)m_i \quad j = 1 \text{ to } J$$

$$\frac{dm_i}{dt} = -\sum_{j=1}^J B_{ji}(r)n_j \quad i = 1 \text{ to } I$$

Here $A_{ij}(r)$ and $B_{ji}(r)$ are the Blue and Red attrition coefficients, respectively. They are developed as functions of the range, r , between Blue and Red units for various tactical situations in the report. Solutions of the resulting differential equations are developed for a few simplified cases.

Fire support is an important area of application for this sort of analysis, but the research is more general in nature and is not designed specifically for fire support.

8. Research Analysis Corporation (RAC) Study⁸

The RAC methodology is straightforward in that it addresses individual aspects of the fire support problem. It is best described by quoting directly from Volume I of the RAC study:

"The products of this study are developed by two procedures. The first formal procedure involves a logical consideration of the implications of threat, military operations, and tasks to be performed for the characteristics and values of fire support systems. The second consists of an exploration and evaluation of some specific fire support system concepts in critical military situations by considering the means available for applying fires, the issues for consideration, a comparative analysis in the particular situation and a sensitivity analysis."

Actually, this study reports little in the way of a structured methodology. The analyses comprise the evaluation of performance and cost data associated with individual phases of combat. The reports present the results with little explanation of how they were obtained. Many of the findings apparently are based on experienced judgment rather than quantitative analysis. However, the reports are rich in insight into the many facets of the fire support system.

9. Stanford Research Institute (SRI)/Balanced Force Requirements Analysis Model (BALFRAM)⁹

The SRI BALFRAM work falls in the same general category as the University of Michigan study, i.e., it is directed toward methodology development rather than analysis of the fire support system. However, it has potential as a basis from which an aggregated fire support system model can be developed.

BALFRAM is a two-sided deterministic simulation that in the past has been used primarily on large scale operations, e.g., global scenarios and multifront campaigns. However, it appears that its logic is also amenable to the higher resolution modeling associated with fire support analyses. The model locates forces at nodes on a grid, notes their objectives, and fights battles using the Lanchester differential

approach. It has decision points that allow for many of the contingencies of the battle, thus providing the two-sided nature.

10. Stanford Research Institute/Marine Corps Attack and Fighter Aircraft Requirements (MAFAR)¹⁰

This study had as its objective the determination of those segments of Marine Corps force operations that can be performed most cost-effectively by Marine Corps attack and fighter aircraft and the mix (numbers and types) of attack and fighter aircraft required. The basic concept of the methodology differs from the other studies researched in that several different analytical approaches were selected and then the results were compared to determine similarities and differences.

The three major approaches were an aircraft mix effectiveness simulation model, a linear programming model, and a game-theoretic model. Additionally, a cost model was used in the cost analysis.

Of particular interest is the method of generating demands on the combat air support system through a sequence of air missions based on inputs of target types, target ranges, and mission categories for both preplanned and on-call missions. The mission sequence is established in time by a Monte Carlo selection routine and distributed according to mission type and time of day.

The study is limited, however, to consideration of strike capable aircraft, which includes aircraft required for offensive air support, air defense, air escort, and support of assault support missions, but excludes aircraft that perform the supporting missions of aerial refueling, ECM, reconnaissance, and command and control.

11. U.S. Army Strategy and Tactics Analysis Group (STAG)
Study/LEGION¹¹

STAG developed a simulation called "LEGION" to test plans dealing with organizations, equipment, and tactics at the division level. However, the STAG reports reviewed for this study deal only with the model development and not with a mix study.

LEGION is an operational war-gaming model in the form of a two-sided, free play (player is free to make tactical decisions), closed loop, man-computer simulation. Each cycle of decisions (by man and computer), computations, and assessments represent 15 minutes of battle action.

The computer makes all tactical decisions at the company level or its equivalent, and below, and the players represent the echelons of command above the company level.

LEGION has been described¹² as a "player-assisted simulation" in contradistinction to the more familiar computer-aided war game because only the highest level decisions are up to the players and the vast majority of the decisions are made by the computer.

12. U.S. Army Combat Developments Command (USACDC) Study/
Legal Mix IV¹³

The Legal Mix methodology is a comprehensive one designed to determine the optimum mix of a division slice of field artillery only. Air support is included but is fixed. Basically, the methodology consists of derivations and comparisons of alternative mixes, using computer simulations and cost data supplemented with military judgment.

The mission list is developed in an innovative way. A base list is established as the norm of intensity. The size of the list is

altered by specifying different intensities in terms of an intensity factor, which also contains a random component.

The analyses conducted include: survivability, mobility, performance against a nonnuclear threat, performance against a nuclear threat, cost, and subjective considerations not adequately addressed in one of the previous analyses. The survivability and mobility analyses were subjective in nature and supported by available analytical data. The nonnuclear performance against the threat was analyzed using the two different methodologies described below, each supported by computer simulations to enable comparison of the resulting mixes. The nuclear analysis also used computer simulations and was conducted to determine if the preferred nonnuclear mixes have an adequate nuclear capability. The cost data used were derived from a cost model developed for the study.

One of the two approaches used the method previously developed in the earlier Legal Mix III study that optimized the total mix for the division slice before assigning the weapon systems tactical missions of direct support, division general support, and force general support by a subjective analysis.

The other approach used approximates the DIVARTY method of optimizing by echelons. First, the direct support requirements are optimized, and then, maintaining the direct support constant, the division general support requirements are optimized. Finally, maintaining the division artillery constant, the optimum force artillery is selected.

13. Weapons Systems Evaluation Group (WSEG) Study¹⁴

The basic concept of the WSEG methodology is to compare the capability of the various weapon systems on the basis of a few measures of performance and costs at a single moment (H+3) of the battle. Comparisons are made by developing estimates of the performance of the weapon

systems on the basis of five parameters: availability, surface survivability, reliability, penetrability, and target kill potential. This is done by analyzing within each weapon type (surface to surface, aircraft, and naval guns) and then selecting a preferred weapon system for a given target type. The results of these analyses for each weapon type are combined to select among artillery, aircraft, and naval guns on the basis of target type.

The analysis procedure contains many qualitative aspects and makes no attempt to account for the dynamics of the battle situation.

The approach used entails four steps:

- (1) Investigation and analysis in defensive operations of Soviet and CPR threats and target arrays
- (2) Determination of a basic matrix that includes: range, size of targets, hardness, AA defenses, and defeat criteria that cover the vast majority of the target array.
- (3) Tabulation of selected classes of targets that must be made ineffective to achieve battlefield objectives.
- (4) Calculation of the effectiveness of the weapon systems under evaluation against the selected classes of targets.

The approaches used in the reviewed studies are summarized in Table 6. In the table, the second column is headed "Optimum Mix Study." The issue addressed there is whether the subject study performed a true mix study as defined in this report; that is, did the study address the question of an optimum mix of supporting arms? Thus, studies that considered only one supporting arm, or considered more but held all except one constant, are not considered true optimum mix studies. Also, studies that analyzed various mixes but made no attempt to select an optimum from the mixes are not identified as optimum mix studies.

Table 6

SUMMARY OF TECHNIQUES USED IN EXISTING STUDIES*

Agency/Study	"Optimum" Mix Study	Supporting Arms				Overall [†] Model for Fire Support System	Key Element Models			
		Air		Naval Gun	Artillery		Mission Generation	System Effectiveness [‡]	Mix Selection	Costs [§]
		Fixed Wing	Rotary							
CNA	No	Fixed	None	Varied	Fixed	No	?	Simulation	No model	Yes (data)
Lockheed/DEMS	No	Fixed	None	None	Varied	No	Map exercise	Simulation	No model	No
Lockheed/USMC	Yes	Varied	None	Varied	Varied	No	Historical data	Simulation	No model	Yes (data)
NWL	Yes	Varied	None	Varied	Varied	No	War games	Simulation	Nonlinear programming	Yes (model)
Ohio State/ DYNTACS	No (model only)	None	None	None	Possible	No	Part of DYNTACS (historical data)	Simulation	No model	No
Michigan	No (model only)	Possible	Possible	Possible	Possible	Possible	Unspecified input	Analytical (Lanchester)	No model	No
RAC	No	Varied	Varied	None	Varied	No	Historical data	?	No model	Yes (data)
SRI/BALFRAM	No (model only)	Possible	Possible	Possible	Possible	Possible	Part of BALFRAM	Analytical (Lanchester)	No model	No
SRI/MAFAR	No	Varied	Varied	None	None	No	Historical data	Simulation	No model	Yes (model)
STAG/LEGION	No (model only)	Possible	?	None	Possible	Possible	Part of model	Simulation	No model	No
USACDC/Legal Mix IV	No	Fixed	None	None	Varied	No	Historical data	Simulation	No model	Yes (model)
WSEG	No	Varied	None	Varied	Varied	No	Historical data	Analytical	No model	Yes (data)

*Some of the model development studies have entries of "possible"; this means that although the particular issue addressed by the entry can be handled by the model, there is no indication that it has been.

[†]A study was considered to have an overall model for the fire support system if it had a single two-sided model capable of handling the whole fire support system.

[‡]System effectiveness includes mission allocation.

[§]A distinction is made under costs between studies that use a cost model for developing costs [indicated by "Yes (model)"] and those that only give cost data [indicated by "Yes (data)"].

B. Evaluation of Strengths and Weaknesses

The strengths and weaknesses prevalent in existing fire support methodologies are summarized in Table 7. It is obvious that the number of weaknesses is significantly greater than the number of strengths. There are three reasons for this. First, it is inherently easier to identify weaknesses in a methodology than to identify strengths. Second, few of the reviewed studies are actually true mix studies, according to the definition used in this report.* Third, the complexity of the fire support system and limited resources tend to force the analyst to make concessions and assumptions that will permit him to attack fire support problems. These concessions and assumptions lead directly to most of the weaknesses listed.

The major weakness in current techniques is the lack of useful two-sided models. This weakness contributes directly to some of the other weaknesses listed in Table 7. For example, unrealistic mission lists result in part from one-sided analysis. When only a single mission list is developed (which is the typical approach) and then is used to evaluate a spectrum of Blue mixes, the results are one-sided and unrealistic. The Red tactician has not been allowed to react to the completely different situation resulting from the introduction of new Blue weapons. There are some two-sided models, notably DYTACS, LEGION, the Michigan model, and BALFRAM. However, none of them are especially suitable for an optimum fire support mix study.

The lack of treatment of uncertainty is also a significant weakness; that many uncertainties are associated with combat is beyond question. Yet many of the analyses are deterministic. The major problem with this is the inability of the analyst to ascribe specific levels of confidence

*For example the NWL and Lockheed/USMC studies.

to the study results. As a result, he has difficulty specifying the risks associated with selecting among alternative weapon mixes.

Table 7

STRENGTHS AND WEAKNESSES OF EXISTING FIRE SUPPORT METHODOLOGIES

Strengths	Weaknesses
Good mission allocation procedures	Unrealistic mission lists
Adequate and varied weapon effects models	Paucity of two-sided models
	Uncertainty often ignored
	Little sensitivity analysis
	Target acquisition often ignored
	Command, control, and communications (C3) inadequately handled
	Logistics support handled simplistically, if at all
	Infrequent use of optimization techniques for mix selection
	Lack of standard MOEs

Some existing studies do treat uncertainty, DYN TACS and LEGION, for example. Thus the techniques for including uncertainty are available. However, the most commonly used technique for modeling uncertainty in large simulations, the Monte Carlo technique, carries with it a penalty in time and costs. The Monte Carlo technique requires several replications of each simulation run. The analyst must decide whether the added information provided by including uncertainty warrants the costs of doing so.

Sensitivity analyses are seldom reported as part of the studies. The NWL study reports sensitivity analyses for particularly important issues at the Mix Preference Selection level. However, having no convenient means for doing sensitivity analyses at the overall system level, NWL had to repeat the bulk of the analytical procedure for each analysis involving changes in major study assumptions, e.g., different scenarios. The only study that especially provides for sensitivity analyses is the Ohio State study, whose analysts developed a separate aggregate model that uses input from higher resolution models to do sensitivity analyses for first-order effects.

The rest of the weaknesses listed in Table 7 are self-explanatory. Along with those described above, they are discussed in greater detail in following sections.

On the strength side of the table there are few entries for the reasons listed above. Mission allocation as done today, utilizing professional judgment, is adequately modeled. The introduction of more automated command and control systems in the future, such as MIFASS, may require new and better algorithms for optimization by selected criteria, but the required techniques are available.

There is a considerable quantity of data in the reviewed studies for weapons effects, much of which can be used directly by other studies. The NWL studies produced hundreds of curves of rounds required versus range for many weapon/target combinations. Given that these data have been suitably validated, they should be valuable for future studies.

C. Alternatives

The introduction to Part II presents the recommended structure of the model hierarchy (see Figure 5). A comprehensive fire support study must at least consider all the elements in that structure. For particular

studies it may be appropriate to leave out some elements or to handle them in a simplistic fashion. However, the impact of doing so should be evaluated by considering the effects on the entire fire support system. There are three levels of models in the hierarchy: an aggregated fire support system model for sensitivity analysis, a detailed model of the entire fire support system for the bulk of the analysis, and a set of supporting high resolution models to provide input to the higher level models. The following discussion presents methods for providing each type of model, including the use of existing techniques and the development of new techniques.

1. The Fire Support System Aggregated Model

Earlier discussions advocate the need for a broad scope, aggregated model for the entire fire support system in the hierarchy of fire support models. The model is to be broad in scope because, to accomplish its objectives, it must account for all aspects of the fire support system in an amphibious operation. It is to be aggregated because its objectives require it to address only the first-order interactions, i.e., the areas of greatest sensitivity, of the elements of the fire support system.

FSSAM has two objectives: to provide a check on the detailed models at the key element level, and to facilitate sensitivity analyses, thereby alleviating one of the weaknesses in fire support methodology delineated in the previous section.

The first objective has special impact if the analysis at the key element level takes the form of most fire support studies. The prevalent approach is to handle the fire support system in pieces, i.e., by key element in an independent fashion. There is an important assumption inherent in this approach; it assumes that the interactions and feed-

backs among the key elements can be ignored. FSSAM provides a means of measuring the impact of this assumption in terms of first-order effects. Another check that FSSAM provides is on the often-used technique of a static mission list, i.e., unchanging missions with changing weapon mixes. FSSAM provides a quick and convenient way of determining the appropriateness of employing a static mission list for specific mix changes in specific fire support situations.

The second objective, sensitivity analyses, stems from the need to extend the analyses at the key element level. Thorough sensitivity analyses are impractical at the key element level. The necessary details of the key element model(s) result in long preparation and running times. FSSAM provides a convenient but not unique approach to this problem. The Ohio State study uses the COMAN model in just this way with its DYN TACS model. DYN TACS is used to develop the input to COMAN, an aggregated model of combat that can quickly test sensitivities of battalion-size operations to a spectrum of contingencies. FSSAM would be used in much the same way--using input from the key element models to test sensitivities over a complete amphibious operation.

FSSAM is not an existing model and would have to be developed, but several existing models exhibit the necessary ingredients. COMAN is the most notable example; it has the same purpose as FSSAM but is designed primarily to support tank combat analysis. The Michigan study approach and BALFRAM also exhibit many of the necessary requirements, but they have not been used for the fire support system. Thus the development of FSSAM can build on and use techniques from existing models with the objective of having a model that:

- (1) Is two-sided
- (2) Is aggregated
- (3) Covers the entire fire support system
- (4) Is compatible with the output of lower level models.

The major problem with the development and use of FSSAM is related to the fourth characteristic. Methods are needed to translate the relatively detailed output of the key element model(s) to the aggregated input required by FSSAM. Firepower scores (with their known weaknesses) and attrition coefficients are typical of the input used by a model like FSSAM. Practical techniques for calculating such numbers are not always available. The Honig Committee* recognizes this problem as well; it lists the provision of adequate measures of performance for aggregated units among the six areas[†] of research most important to improving combat modeling.¹²

2. The Key Element Model for the Fire Support System

The bulk of the fire support analysis is done at what has been termed the "key element" level of the fire support system. The procedures used at this level comprise the key element model or models. These models receive detailed input from the supporting high resolution models and provide aggregated output in final form for the decision-maker, as well as for FSSAM. Analysis procedures at the key element level most often comprise a series of separate models for the four key elements. The mission list generation element is the element that is most frequently separated from the rest of the elements for analytical purposes. Mission allocation and systems effectiveness, on the other hand, are often combined. Optimum mix selection is so infrequently done quantitatively that there is no trend

* A select Army review committee, headed by Dr. John Honig,¹² which in 1971 reviewed a number of current Army models designed to assist in analyses of force level, force structure, force mix, and weapon systems analysis problems.

[†] The other five areas are: target acquisition, night operations, information processes, suppression and neutralization, and the decision process.

to be cited. In the only reviewed study that did develop a quantitative approach, NWL handled it as a separate model.

It has been pointed out that this separated analysis creates problems concerning interactions and feedbacks. If these shortcomings can be accepted for a particular problem, then an approach like NWL's can provide a viable basis for the key element analysis. Section III, below, provides a comprehensive review of the possibilities of such an approach to this portion of the model hierarchy, and it will not be pursued further here. The remainder of this section is devoted to the possibility of an alternative approach--a unified approach called the "Dynamic Fire Support System Model (DYFSS)."

a. Description of the Unified Approach--
Dynamic Fire Support System Model

The motivation for treating the fire support system in a unified way is to have a means for handling the interactions and feedback loops of the system directly. A schematic of the suggested approach is shown in Figure 6. The approach shown is basically the same as that taken by STAG with its LEGION model. It is a player-assisted simulation that allows players to make the "important decisions" and leaves the rest to the computer. This approach is appropriate to a specific type of fire support study. It applies to those studies undertaken to select among a set of alternative mixes or to optimize over a spectrum of weapon mix possibilities. Thus, a set or spectrum of mixes is assumed as input for DYFSS. These may be provided by previous studies or the study directive, or they may be developed by a supporting model/procedure for DYFSS.

DYFSS is envisioned as a unified two-sided model that handles the important feedback loops of the fire support system. The two important feedback loops are those shown in Figure 6. The first represents the dynamics of a battle. Many studies model the forces of

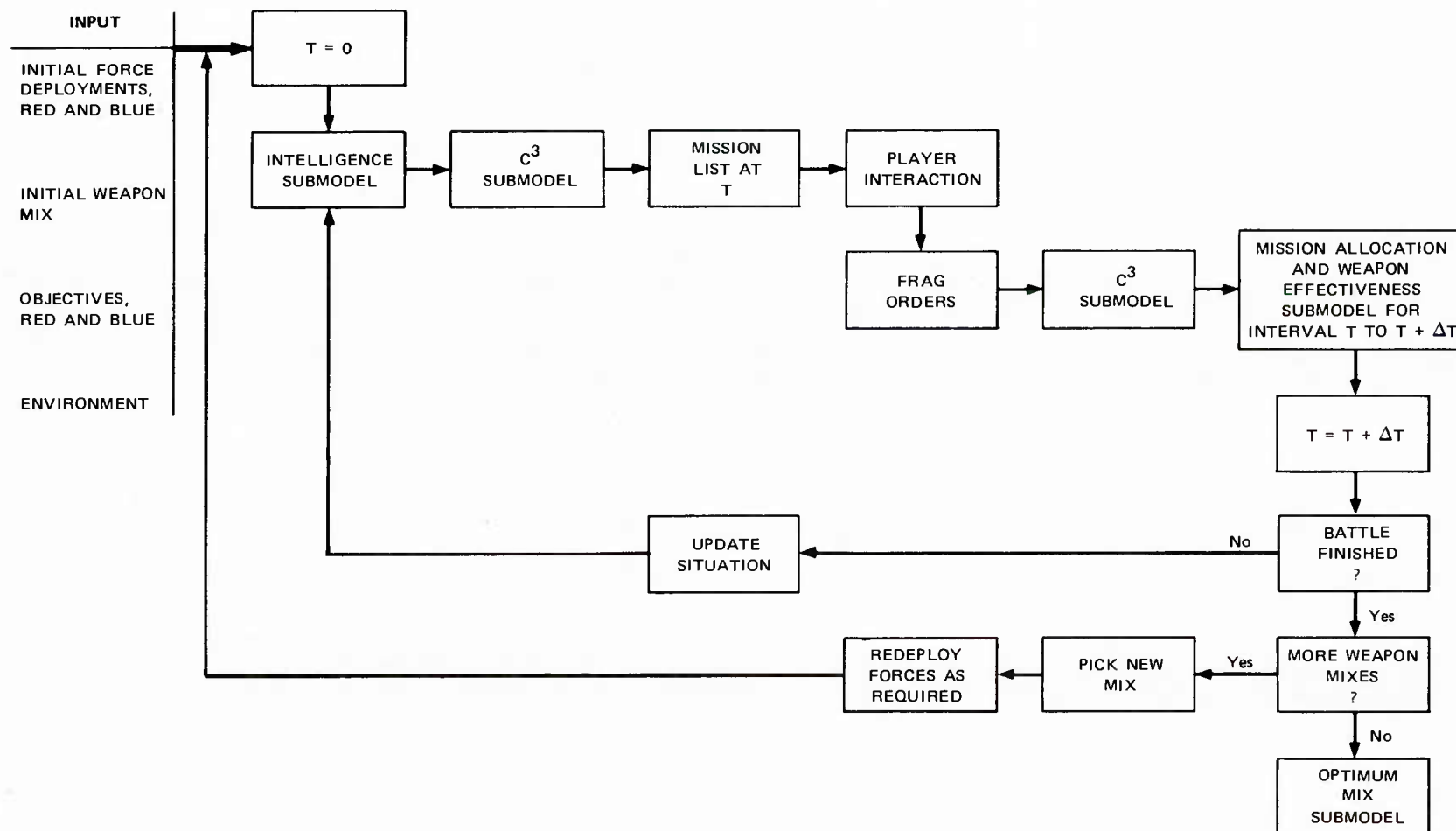


FIGURE 6 SCHEMATIC FOR THE DYNAMIC FIRE SUPPORT SYSTEM MODEL (DYFSS)

one or both sides as fearless by assuming that they pursue their appointed objectives by a preplanned route and schedule no matter what happens. By reassessing the tactical situation at regular intervals (LEGION uses 15 minutes), this unrealistic representation can be avoided. The second feedback loop results from the fact that the deployment of the forces of both sides depends on the weapon systems available to each. Thus, when a new weapon mix is to be evaluated, the deployment of both sides should be analyzed to ascertain if any changes should be made.

DYFSS comprises four submodels and their interfaces. The submodels are Intelligence, C³, Mission Allocation/Weapons Effectiveness, and Optimum Mix. Two of these (Intelligence and C³) have the same names as two of the supporting models shown in Figure 5, but they are in fact different. The submodels of DYFSS will be much more aggregated. They will depend on the high resolution models for input, just as the Mission Allocation/Weapons Effectiveness Submodel depends on the high resolution Weapons Effects and Logistics models.

The Intelligence and C³ Submodels do not exist in the form required for DYFSS and therefore represent a development item. The player interaction interface has been used before, for example, with LEGION. In LEGION, information regarding the enemy situation is provided each player through the Surveillance Submodel. Inputs to the model consist of the location, activity, resources, and previous surveillance results for all units in the game. The output consists of a coded target list for each unit that specifies which enemy units have been detected and how much is known about them. Fire support units may acquire targets of their own, as well as be assigned targets by other units.

Several models suitable for the Mission Allocation/Weapon Effectiveness Submodel of DYFSS are in existence. They are discussed below in Section IV.

The Optimum Mix Submodel is a cost/effectiveness model that combines the cost data from a supporting cost model with the effectiveness data provided by the other DYFSS submodels to pick an "optimum" mix. NWL's combination of regression techniques with a nonlinear programming model to perform fixed effectiveness, minimum cost analyses is by far the most ambitious in this area. In fact, the NWL study was the only study reviewed that attempted to determine optimality in a formal quantitative way. The other studies either made no attempt to find an optimum mix or did so in a simplistic way. For many of these studies this was appropriate, considering the manner in which they developed cost and effectiveness data. The selection of an optimum requires considerable subjective judgment because it entails trade-offs between effectiveness and costs. As a result, unless special precautions are taken, it is generally difficult to combine effectiveness and costs in a meaningful way. The approach taken in most of the reviewed studies is an appropriate one, given the type of cost and effectiveness data they developed. Cost and effectiveness data are developed separately and presented separately. If any selections of preferred mixes are made, they are made on a subjective basis.

To combine cost and effectiveness in a way that permits the selection of an optimal mix on a more objective basis, either fixed cost or fixed effectiveness techniques should be included in the selection process. If possible, such techniques should be included in DYFSS. The exact form that the Optimum Mix Submodel takes in DYFSS depends on the type of results that the analyst wishes to present the decision-maker. The NWL Mix Preference Program is directly applicable to this part of the methodology and is discussed in detail in Section V, below, and Appendix C.

b. Problem Areas of the Dynamic Fire Support
System Model

There are problems associated with the development of DYFSS. First, as noted above, several of its submodels must be developed. Second, models like DYFSS can easily become impractical as a tool for comprehensive analysis, as has been the case for LEGION in the opinion of the Honig Committee.¹² They feel that LEGION attempts to model so many aspects of combat that the input preparation efforts and the running times are too long to use LEGION as an analytical tool. Thus, should DYFSS be developed, this problem should be avoided by including only those aspects of the fire support system that must be in the loop. This would be done by leaving as much detail modeling as possible to the supporting models that provide input to the submodels.

A third problem with the DYFSS approach can also be considered one of its strong points, i.e., the existence of players in the loop. The number of such players needed depends on how detailed the higher level command and control structure is simulated. LEGION, which uses players for all decisions above company level, employs 30 to 50 people to play about 20 hours of battle in one week. Also, the use of players introduces an unquantifiable random element that makes the representativeness of the results of a single run of DYFSS questionable. Thus several runs with different players or different assignments of the same players may be required.

These are all problem areas that must be weighed when deciding on either the unified approach to modeling the fire support system (i.e., DYFSS) or the independent element approach discussed below in Sections III through V. However, if DYFSS can be developed in a form that makes it practical for analysis, it should be preferred because of its greater inherent realism.

3. Supporting Models for the Fire Support System Model

As shown in Figure 5, the lowest level, highest resolution models are those that support the model(s) at the key element level by providing much of the input they required. Six such supporting models are needed:

- Intelligence
- C³
- Logistics
- Weapons Effects
- Mobility
- Costing.

These models address each of their subject areas in detail, independent of the main stream of the fire support analysis. In fact, the test of whether a model is deemed a supporting model is whether or not it is part of a side analysis that is charged either with addressing a specific part of the problem or with providing specific input to higher level models. Those aspects of these six areas that must be included as a dynamic part of the fire support analysis are included in the higher level models.

All six models are addressed in subsequent sections of the report and in Appendix C. The techniques in use, their strengths and weaknesses, and, where appropriate, alternatives for them are discussed below in connection with the key elements each model supports in Sections III through V.

III FIRE MISSION GENERATION

This section, as well as Sections IV and V, addresses the fire support system hierarchy of models at the key element level. The modeling of the key elements is treated in a separable way, in contrast to the unified approach of DYFSS described in Section II. Addressing the key elements in this way affords a convenient format for reviewing past studies on fire support, as well as providing the basic framework for the compartmentalized approach to modeling the fire support system. The compartmentalized approach is at a lower level of aggregation than DYFSS but at a higher level of detail. These approaches are neither inconsistent nor incompatible but represent separate stages in the evolution of a comprehensive methodology. DYFSS can utilize the more detailed definition of the separated or compartmentalized approach to build upon.

A. Techniques in Use

Fire mission generation has been described in Part I and is perhaps the key portion of a fire support methodology. It drives subsequent portions of the methodology because it determines the quantity of fire needed and when and where fire is needed. It is vital that representative target arrays be developed if study results are to be usable. Unfortunately, the generation of credible fire missions based on these target arrays appears to be one of the weakest areas of fire support analysis.

There are two basic steps in the development of the target mission list for presentation to the weapon mix. The first is to develop a chronology of the locations of enemy forces, personnel, and facilities with respect to friendly forces. This chronology is called the actual target

array. The second step is to translate this array of the hostile force into a list of targets to be presented to the friendly weapon systems. The first step produces a chronology of the "real" enemy positions, and the second produces a chronology of where the Blue fire control officers think the targets are. Putting it another way, the first step entails determination of the effects on the target array of interactions of opposing forces, and the second step entails determination of how Blue's observers and sensors detect and locate targets and then pass on the information to the fire control officers.

1. Fire Support Actual Target Arrays

Table 8 summarizes the approaches taken by the reviewed studies that had target arrays associated with them. All the techniques used, except the Ohio State study approach, can be classified under one of two headings--war games or historical data. Ohio State's DYN-TACS develops an array dynamically, i.e., the array is generated as an integral part of a simulation. In the other studies the array generation is separate from the other portions of the evaluation procedure.

The war game approach generally entails the use of several military officers simulating the actions of Blue and Red commanders. A scenario provides the objectives that guide the decisions of both sides. Typically, the Blue and Red force commanders are in different rooms and communicate through a referee. Actions are generally simulated in great detail, e.g., single weapon against single target, and the outcome of such an engagement is determined by a random number table (Monte Carlo technique).

War games typically take several days or weeks to simulate a few hours of combat. Computer-aided war games such as STAG's LEGION are designed to reduce this time. LEGION simulates everything below company

Table 8

SUMMARY OF TECHNIQUES FOR FIRE SUPPORT TARGET ARRAY GENERATION

Agency/Study	Method Used
CNA	Used enemy order of battle for total force structure. No indication of how the fire support mission array data developed from this.
Lockheed/DEMS	Campaign planning generates phase lines versus time. Targets in each phase are developed by map exercise. Target list for each phase is independent of previous phases.
Lockheed/USMC	Array developed by military judgment.
NWL	Arrays developed from war games (one array for each of 4 war games).
RAC	Array developed from historical data and military judgment.
SRI/MAFAR	Model develops the array from an input distribution specifying the likelihood of specific target types (up to 99). Monte Carlo methods are used.
USACDC/ Legal Mix IV	A base fire support mission array specifying the number of fire missions by type is developed from historical data. These numbers are multiplied by an "intensity factor," K, which is a measure of the conflict intensity. Also contained in K is a random component that is used by Monte Carlo methods to determine the exact number of targets of each type for each model replication.
WSEG	Fire missions are developed using the enemy order of battle and historical data. Targets are those at a specific time, i.e., H+3.
STAG	A computer-aided war game simulates a two-sided engagement. Targets result directly from input and man/machine decisions.
Ohio State U.	The DYN-TACS model generates a dynamic fire support mission array as part of the model. The placement of units at the beginning of the battle is an input.
U. of Michigan	The fire support target array is not developed as part of Michigan's approach but is assumed available as an input.

level on the computer, and at higher levels players make the decisions. The model simulates surveillance, move and fire decisions, assessment, administrative support, and air action functions over a 15-minute battle period. Then the players reassess the situation, make decisions, and LEGION is used to simulate another 15-minute period.

Historical data provide the second major source of target arrays. (The use of military judgment as the sole source of an array, as in the Lockheed/USMC study, is considered essentially the same as the use of historical data since such judgment relies on personal samples of historical data.) In this approach the employment of forces in past campaigns is investigated to glean the details of the array. The resulting information generally takes the form of deployment densities and maneuver time schedules for troops and equipment. Most often these data are then translated into specific deployments and movement patterns by means of a map exercise. However, in some studies the densities are used directly, as, for example, in the WSEG study.¹⁵

The methodology employed in the Legal Mix series of fire support studies makes use of a novel approach to mission array generation. It relies on historical data but adds an "intensity" factor, K_I , that adjusts a base set of data to conform to an indicated intensity of the conflict. The base data are established for a particular environment in Europe by means of historical data. This base then acts as a norm against which higher or lower intensity conflicts are defined by raising or lowering numbers of units involved by the amount specified by K_I . The fractional part of K_I is used along with Monte Carlo techniques to include the random element in the mission array. For example, if the base data predict that there are N tanks in the mission array and a K_I of 2.25 is used, then there will be at least $2N$ tanks in the conflict and there is a 25-percent chance that there will be $3N$ tanks. The Legal Mix reports indicate that this approach has provided very satisfactory results.

2. Fire Support Target/Mission List

a. Target Acquisition and Command and Control

The second phase of the fire mission generation procedure is the translation of the actual or true fire support target array into a friendly force fire support target/mission list. This list is a chronology of weapon systems missions as viewed by Blue fire control officers. The development of the list entails specifying sensor systems to determine how a target is detected and located and defining the C^3 structure to determine how this information gets to the fire controller. Table 9 summarizes how this subject is treated in the reviewed studies.

The entries under the heading "Handled Directly" indicate whether target acquisition and C^3 are integral parts of the analysis. Thus an answer of "No" does not necessarily mean that these functions are not addressed; it may mean that they are handled in an aggregated way or as part of a separate analysis and the results thereof are provided as inputs.

Most studies reviewed, most notably those that address the overall mix problem, do not handle target detection and C^3 directly. Typically, they handle these aspects of the fire support system in separate analyses that do not interact directly with each other or with the elements of the main stream of the fire support analysis procedure. In the NWL, Dahlgren, study, for example, target acquisition and C^3 are confined to the war games. However, the analyses of alternative mixes were made after the war games were completed. This means that the target acquisition system and C^3 structure that produced the mission list are unaffected by the different mixes.

Some studies assume that target acquisition and C^3 work flawlessly, which is equivalent to ignoring them. In such studies information and orders are communicated perfectly and without delay. Still

Table 9

SUMMARY OF TECHNIQUES USED TO DEVELOP THE TARGET/MISSION LIST
FROM THE FIRE SUPPORT TARGET ARRAY

Agency/Study	Target Acquisition		Command and Control	
	Handled Directly	Technique Used	Handled Directly	Technique Used
CNA	No	A percentage of detected targets (by type) is applied to the mission array	Yes	Command and control chains are modeled and produce a response time for each chain
Lockheed/DEMS	No	Discovery times that are supposed to include times for detection and acquisition are part of the input to DEMS	No	Delay times are input to the model
Lockheed/USMC	No	Estimated acquisition probabilities by target type are given as model input for each sensor	No	None
NWL	No	Handled in the war games by Monte Carlo methods	No	Time for mission accomplishment includes command and control delays
Ohio State U./ DYNTACS	Yes	Detailed models of observers and detection systems are a part of DYNTACS	Yes	Communications links are modeled in detail. Monte Carlo techniques are used to develop delays for each message.
U. of Michigan	No	A formulation including a factor for intelligence is developed but abandoned because of a lack of data	No	Assumed perfect command and control
RAC	No	A fraction of targets detected is specified for each target type	No	Not addressed
SRI/MAFAR	No	Target acquisition is one factor that goes into the determination of the input target frequency of occurrence	No	Time for mission accomplishment includes command and control delays
SRI/BALFRAM	No	A probability of detection of an entire unit is specified, given a recon capability	Yes	The decisions made by the commander can be modeled, including delay times under varying contingencies
STAG/LEGION	Yes	The relationships between every Blue and Red unit are examined. Detection probabilities are gamed for individual sensors.	Yes	All communications between company and battalion are simulated. The command and control structure above company level is manned by players.
USACDC/ Legal Mix	No	Probabilities of detection are entered from a side analysis to the main simulation	No	A constant processing time is added to the total system reaction time to account for C ³
WSEG	No	A list of system response times, including target acquisition times, is given	No	Not addressed, as such.

other studies handle these aspects of the fire support system by applying degradation factors to target location information and system reaction times.

The Ohio State DYNTACS model and STAG's LEGION are the only models that handle both acquisition and C^3 directly. They evaluate individual sensors and target pairs for acquisition and handle C^3 by modeling the communication links connecting sensors, command, and weapon systems. The modeling is accomplished by simulations in both these studies. Because of their thorough treatments of acquisition and C^3 , these two efforts are described further below and described in more detail in Appendix C.

One of the basic modules of DYNTACS is the Intelligence Model. It simulates the intelligence process and therefore the target acquisition process for all combat elements, including indirect fire ballistic weapons. At any given point during the battle, each combat element has an "intelligence" list of the enemy weapons it has pinpointed, visually detected, and approximately located.

Visual detection as represented in DYNTACS encompasses the entire process of search, detection, recognition, and identification. Crossing velocity of the enemy element, apparent range, scene complexity, and whether the observer is moving are the variables that determine a detection rate, which in turn becomes a parameter in an exponential probability distribution for the time of detection. Detection rate is modified if the observer has prior knowledge of the approximate location of the element. The search process for an enemy element ends when an enemy weapon is newly detected. All intervisible enemy weapons within a specified area of the newly detected target are assumed to be detected.

The acquisition of targets may also occur through "pinpointing" when the enemy weapon is concealed or camouflaged. Pinpointing consists of placing a weapon's sights on a firing weapon's signature, i.e., smoke, dust, or flash. The pinpointing process is simulated through a Monte Carlo operation using inputted probabilities.

In the Surveillance Submodel of LEGION, the relationships between every pair of Red and Blue units are examined to see if interaction is possible. Every target is put into one of the following categories:

- A new target that has just moved into the area of observation.
- A continuing target that remains in the area of observation.
- A previously observed target that is no longer in the area of observation.

Detection is gamed by considering the type of sensors (visual, aural, or radar) available versus the detection class (e.g., personnel, wheeled vehicle, tracked vehicle, aircraft), the number of elements in the detection class, their activity and range from the observer, and environmental factors such as vegetation and weather.

DYNTACS pays a great deal of attention to the timing and the communications aspects of C^3 in the simulated combat. The Communications Module simulates the information flow to unit commanders, to individual combat elements, and to fire support elements. Considering the fire support activities, the model "...enables the military planner to consider the limitations and capabilities of the tactical communication nets to transmit messages as required when predicting the relationship between tactical unit performance and...fire support response-time delays...."¹⁶ Messages are grouped into intelligence, fire request, or tactical messages. The model represents the message transmission time by a log normal distribution and a Monte Carlo procedure. The various

nets can be busy, and therefore a queuing system is simulated with an inputted maximum length for a sender. The next sender is chosen randomly when a busy net becomes available. Communication between the forward observer and the fire direction center of initial fire requests and aim adjustments is simulated in the Indirect Fire Ballistic Weapons Model.

In LEGION, the Communications Submodel simulates all communications from the company (computer modeled) to the battalion level (war gamed). The activity and status of a unit within the game can be communicated to the players with varying delivery times. Factors considered in the communication process include, among others, range, line of sight, weather, reliability, interference, movement, and fire effects. These factors are assigned weighting values to determine ultimately the delivery time.

b. Composition of the Target/Mission Lists

Table 10 gives a synopsis of the information contained in the target/mission lists of the reviewed studies. Several studies (like RAC's and WSEG's) did not develop target/mission lists in the sense used here and therefore are not included in the table. The studies shown in the table developed lists of targets as they would be presented to the weapons coordination officer for allocation to a weapon. He makes the allocation decisions using the information in the lists as the sole source of target information.

The headings given in Table 10 are defined as follows:

True Location--The actual coordinates of a real target.

Detected Location--The coordinates of a target (perhaps false) as seen by the detector or observer.

Zone of Responsibility--Identification of the weapon responsible for the area in which the target is detected.

Table 10

TARGET/MISSION LIST INFORMATION

Agency/Study	True Location	Detected Location	Zone of Responsibility	Range to Friendlies	Appearance Time	Duration*	Priority	Supporting Arms Preference	Coverage Desired	Aircraft Delivery Mode	Location Accuracy	Mission Type†	Defenses	Size	Hardness	Detector Type	Direct Fire Candidate	Personnel with Target	Environment	Posture
CNA	X		X		X	X	X					X				X	X			
Lockheed/DEMS	X			X	X	X	X		X		X	X	X	X		X		X		
Lockheed/USMC	X				X	X	X				X	X		X	X	X				
NWL		X	X	X	X	X	X	X	X	X		X								
SRI/MAFAR	X				X	X						X								
STAG/LEGION		X					X													
USACDC/Legal Mix	X	X		X	X‡	X‡	X‡		X		X	X		X‡				X	X‡	X‡

* Estimated by observer.

† For several studies specifying mission type determines many of the other characteristics listed in the table, such as size, personnel, and hardness.

‡ For each of these there are two values given. One is the actual value and the other the observer's or sensor's estimated value.

Range of Friendlies--The distance from the target to the nearest friendly troops, usually the FEBA.

Appearance Time--Time at detection.

Duration--Time interval the target can be observed (sometimes given as disappearance time).

Priority--An indication of the relative importance of a target at the time it is detected.

Supporting Arms Preference--A ranking of air, naval gunfire, and artillery as to which is best suited for the target.

Coverage Desired--An indication of the level of damage desired.

Aircraft Delivery Mode--The mode desired for delivery of aircraft ordnance.

Location Accuracy--The location accuracy attributable to the detection device or observer.

Mission Type--An identification of the type of target or mission.

Defenses--A specification of the type of defenses at the target.

Size--Target size.

Hardness--Target hardness.

Detector Type--An identification of the source of the detection (observer or sensor system).

Direct Fire Candidate--A specification of whether the target can be taken under direct fire.

Personnel with Target--An indication of whether personnel are with the target.

Environment--An indication of the makeup of the local terrain: percentages for towns, woods, and open space.

Posture--An indication of personnel posture distribution: percentages for standing, prone, and in foxholes.

As can be seen in the table, some target characteristics appear in most of the studies. They represent the information that must be included in any useful mission list: target location (with or without

error), appearance time, duration, priority, and mission type. The other characteristics add valuable information and result from the specialized approach taken in specific studies. The inclusion of a "supporting arms preference" in the NWL study, for example, results from the way in which candidate fire support weapon mixes were derived. In the manual war games, each target was reviewed to specify a rank ordering of supporting arms for that target.

B. Evaluation of Strengths and Weaknesses

1. Fire Support Target Arrays

The previous subsection describes the techniques in use today for fire mission generation. This subsection evaluates the strengths and weaknesses of these techniques in view of the requirements of future USMC fire support studies. The goal of the evaluation is to provide USMC planners with a knowledge of which areas of the methodology are strong and which are weak. In this way the planner can determine what such weaknesses mean to his study and what he should do about them. Certain areas of weakness may be immaterial to or acceptable for a particular study and therefore require no remedial action. This is often the case with a comparison of alternatives that differ only in some respects; areas of no difference generally require little, if any, analytical treatment. Other weaknesses will demand careful attention when they fall in critical areas of the analysis, i.e., areas in which the alternatives differ significantly.

One drawback to the acceptance of the results of recent fire support mix studies has been the fire mission generation procedures used. As indicated in the previous section, these procedures fall into one of two categories--war games and the use of historical data. Table 11 gives, in general terms, the strengths and weaknesses of these two approaches.

Table 11

STRENGTHS AND WEAKNESSES OF TARGET ARRAY
GENERATION TECHNIQUES

	War Games	Historical Data
Strengths	<p>High degree of realism resulting from human judgment</p> <p>Great detail possible</p> <p>Two sided</p>	<p>A measure of realism based on the use of actual battle data</p> <p>Gives numbers and ranges of target types</p> <p>Ease of use</p>
Weaknesses	<p>Many players and controllers needed</p> <p>Time and money consuming</p> <p>Limited flexibility for excursions</p> <p>Gives single sample of a random process</p>	<p>Less realism than war games</p> <p>One sided in use</p> <p>Shortage of adequate data</p> <p>Possibility of biased data</p> <p>Difficult to adapt to new systems and concepts</p>

a. War Games

War games are often a preferred approach because they provide the realism of including the human to make most decisions. By comparison, faithful computer simulation of human decision processes is extremely difficult and as a result is typically handled in a simplistic fashion. Other areas of strength associated with war games are the capabilities of handling great detail and providing a two-sided game.

The major weakness of war games is the severe requirement they create for time and personnel. They are very time consuming, often taking months to simulate a few days of combat. Most war games use computers to reduce the amount of time required to complete a game, but in

many cases the time and costs still remain high. As a result, war games are generally only played once, which limits the flexibility of the war game approach to changing tactics and doctrine.

Random events occurring in war games are generally handled with Monte Carlo techniques. For example, a randomly chosen number is compared with the probability of kill of a missile to determine whether a kill has occurred for any given missile shot. As a result, the history of a single play of war game is just one realization of a stochastic process. If only one pass through the war game is made, then there is little indication of the representativeness of the results. It may be that the single realization obtained is a very unlikely result and therefore far from representative. In such a case the results are not an appropriate basis on which further analysis should rest. The question of whether a change in the value assumed by some random variable at the beginning of a game may have changed the answer significantly may not be answerable from the results of a single pass. Similarly, there is the question of whether a different set of players (or even controllers) would produce a significantly different result. Just a second pass would provide some insight into the answers to these questions.

Generally, the assumption is made that enough random events occur in the war game so that the vagaries due to choices of highly unlikely values for some random variables are damped out. There is intuitive appeal in this argument, but its validity has not been proved. The assumption rests on another assumption, i.e., that for all practical purposes the random events can be considered independent. If they cannot, then the validity of just one play is questionable.

Another and perhaps more significant drawback attributable to the inflexibility and resulting single pass nature of a war game is found in the way war games are used to generate fire support target arrays.

Typically, study teams develop a single array from a scenario or war game by assuming a particular mix of fire support weapons. Then, without changing the array, the relative benefits of various other weapons and mixes are compared in terms of how well they handle the missions in the original array. The troublesome assumption inherent in this approach is that the actions of the other side are independent of changes in the weapon system, or, in other words, that the Red forces act the same no matter what type of weapon mix they face. This in effect makes the target array one sided, because Blue can change his tactics and weapons but Red cannot. The one-sidedness of the procedures is not unique to fire support mix studies; it is a common weakness of many tactical weapon studies. Nevertheless, it detracts significantly from the acceptability of mix study results and is a primary concern in the development of a viable mix evaluation procedure. How critical the assumption of the validity of a fire support target array generated in this way is depends entirely on the particular problem under analysis. The analyst must make this judgment for himself. However, the general rule is that the greater the differences among the alternate weapon mixes, the more tenuous the assumption.

b. Historical Data

Historical data also provide a measure of realism by virtue of drawing on actual battle data. Historical data are generally given in the form of distributions because they are derived from various battles. This type of data allows the analysis to be carried out for a range of target arrays. The intensity approach taken in the Legal Mix study represents an especially good example of this; it provides not only a convenient mechanism for testing the sensitivity of results to the intensity of the conflict, but also a method of treating the uncertainty inherent in the size of the threat.

Another advantage of historical data is that their use provides considerable flexibility. In comparison with war games, historical data are flexible for analysis of a changing environment. Their use entails merely selecting the appropriate data (assuming that they exist).

The weaknesses in the use of historical data are: a lack of realism in comparison with war games; an insensitivity to changing situations that can result in a one-sided array; a paucity of good data; a distinct possibility of biased data; and, since the data are often 20 and 30 years old, an inability to adapt to new systems and concepts. The first two weaknesses are closely related. Because the data are derived from history, they may not reflect today's tactical thinking, let alone tomorrow's. The conditions will never be the same as those from which the data resulted. Thus, historical data suffer from a lack of the realism that a two-sided war game can develop by seeing how players adapt to new concepts and systems.

The lack of satisfactory data for the development of target arrays will always exist. Sources of such data are basically wars, war games, and tactical exercises. However, the exact sources of the historical data used in the reviewed studies are not given. This creates a problem if the analyst attempts to use their target arrays because the precise environment from which they are derived--specifically, how it differs from the environment under study--is not known.

The introduction of innovative concepts and systems into the fire support problem creates problems for any fire support target array generation procedure. The procedure must be adaptable to such concepts and systems, and total reliance on historical data can lead to erroneous results. War games also suffer from this constraint, but they can more readily adapt to such changes. It is more difficult with historical data unless the analyst has detailed knowledge of the environment that generated the data.

2. Fire Support Target/Mission List

a. Target Acquisition

Target acquisition is an area of weakness in many studies, including fire support. In fact, the Honig Committee,¹² having reviewed several army combat models, concluded that target acquisition is one of the major weaknesses in the modeling state of the art and an area in which a considerable portion of future modeling effort should be concentrated. In particular, they found treatment of acquisition by units (e.g., squad versus platoon) lacking. The findings of this study support that conclusion although the Marine Corps has done some work in this area at Quantico in connection with war gaming. Target acquisition is generally not adequately handled in current fire support methodology.

Two of the reviewed studies, the Ohio State DYN-TACS and the STAG LEGION Models, are capable of handling many aspects of target acquisition (see Table 9). Detailed submodels are included as part of these simulations. However, neither model is equipped to handle all aspects of the fire support mix problem and neither of them addresses unit-by-unit detection.

Studies that use war games, such as the recent NWL work, generally handle target acquisition with input probability of detection curves and Monte Carlo techniques in the war games. Consequently, they do address acquisition, but the results suffer from the same war gaming problems as do the results of the target array generation procedures. They generally represent only a single realization of a stochastic process and are insensitive to changes in weapon systems and sensors. As a result, they are inflexible and often inappropriate for the comparison of weapon mixes.

How important the methodological weaknesses in target acquisition are to a study depends on the objectives of that study. If the objectives include the evaluation of alternative weapons or mixes,

then they can be very important. The question that must be answered is: Do these alternative systems or mixes display significant differences in the way they contribute to or depend on target acquisition? If they do, then the way in which target acquisition is handled can be very important and an adequate procedure must be included in the methodology.

In the study of overall fire support requirements, it is important to examine the target acquisition capability attributable to different weapon mixes to determine if any differences exist. For example, aircraft carry sensors as well as weapons, but artillery relies on sensory systems separated from the weapons themselves. Attempting to establish optimal mixes of air, naval, and artillery systems without considering target acquisition ignores this difference and can place one or another of the supporting arms in a disadvantageous position. The relationship between changes in supporting arms and changes in target acquisition systems would almost certainly not be proportional. In some cases where differences in target acquisition capability are found, the differences may be insignificant; in other cases, they may be significant.

b. Command, Control, and Communications

Two factors determine how C^3 affects the contents of the mission list: the speed with which information is passed from the system or person detecting the target to the weapon systems capable of attacking it, and the accuracy with which the information is passed. Both factors depend strongly on the mechanism that processes the information, but most studies address only the speed factor.

Delay times for C^3 are handled in detail in several of the reviewed studies (see Table 9). Some of the studies simulate the fire support command chain in detail to develop realistic estimates of the time it takes to pass information. Studies that use war games are the

strongest in this area because the players add a realism to the decision-making process that cannot be realized with a simulation.

Most of the reviewed studies ignored the accuracy with which the command chain passes the information. How important this weakness in the fire support methodology is depends on the objectives of the study. In many studies the accuracy of command and control information is independent of the weapon mix and can be ignored or handled in an aggregated way. However, future fire support systems will operate with much more sophisticated communications and data processing equipment than those in use today. If future systems are to be compared with current systems, then the procedure for comparing them must address the C³ structure in detail, including the accuracy as well as the speed of operation.

c. Contents of the Target/Mission List

Table 12 provides a synopsis of the contents of the mission lists that were developed as part of the reviewed studies. This table is presented to give an indication of the relative sizes of the studies reviewed for this study. It also serves to point out a problem encountered in assessing these studies--a problem that constitutes a weakness in the procedures for developing fire support target arrays and lists. Despite the fact that many of the studies use situations that take part in similar parts of the world with comparable force sizes, the analysis generates campaigns of significantly different lengths and target/mission lists of significantly different sizes and compositions. Thus, although most of these studies address the same general questions, they do so with considerably different input. This inconsistency makes it difficult to evaluate the relative merits of the various target lists. More importantly, it weakens the acceptability of the results of all the studies when their inputs are viewed together, as they are in Table 12. If all the studies reach the same conclusions, then the conclusions depend little

Table 12

SUMMARY OF SOME TARGET ARRAY STATISTICS

Location	Study										
	CNA		Lockheed/ DEMS	Lockheed/ USMC	NWL				USACDC	WSEG	
	Europe	SEA	Asia	SEA	Asia	Asia	Latin America	Latin America	Europe	Asia	Europe
Divisions*											
Blue	1+	1+	3+	1+	1+	1+	2+	2+	1+	--	--
Red	2/3+	1+	3	1+	1+	1+	1+	1+	--	3	5
Battle length (days) [†]	4	4	9	9	8	2	2	2	1	Snap- shot	Snap- shot
Total target and missions [‡]	410	494	1159	2045	1409	418	804	672	3428	320	630
Personnel (%)	47	20	72	37							
Point (%)			14	29							
Hard materiel (%)	33	50	6							6	18
Soft and medium materiel (%)	20	30	1							94	82
Targets (%)					45	47	47	71	80		
Missions (%)			7	34	55	53	53	29	20		

* The plus signs given indicated that divisions are reinforced or supported by additional forces.

[†] USACDC states that their one day of simulated battle is equivalent to 1-1/2 to 6 days of actual combat.

[‡] The breakout of targets by type uses the terms employed in the studies themselves. Also, the WSEG breakout includes personnel under "Soft and Medium Materiel" targets.

on the input. If the studies reach different conclusions, which one used the correct input?

C. Alternatives

1. Fire Support Target Array Generation

It was established in the previous section that fire support target array generation procedures suffer from a lack of realism that is primarily the result of not adapting Red targets to changes in Blue weapon systems and mixes. In other words, array generation procedures are one sided. Another factor detracting from arrays developed by current techniques is their inability to portray uncertainty. Combat is in reality an uncertain process; thus to model it without uncertainty detracts from the realism of the model. Uncertainty should be accounted for in a comprehensive fire support methodology.

It is clear that there is a need for techniques that allow the development of more realistic target arrays. However, developing such techniques is not an easy task. The fact that unsatisfactory techniques prevail in current fire support studies attests to the difficulty of developing approaches that are two sided and capable of handling uncertainty. The basic problem is that detailed modeling of large scale combat operations is difficult, if not impossible.

Section II, above, outlines a potential approach that addresses the entire fire support system. That approach uses a unified model, DYFSS. The model is called "dynamic" partly because it handles the mission list as a changing entity that reflects the battle progress and the weapons systems involved. In other words, DYFSS is two sided. In this discussion, the more traditional key element approach is being considered wherein the fire support mission list is developed separately from the other key elements. It lacks some of the realism of the DYFSS approach but has the

advantage of having been used before. The purpose here is to suggest alternatives to current techniques that can improve their realism. Detailed investigation of these ideas has not been pursued; they only represent viable candidates bearing further investigation.

The following alternatives offer promise as means of generating better fire support target arrays:

- Extending the use of computer-aided war gaming.
- Application of two-sided computer models to fire support mission list generation.

The first alternative is an extension of current techniques, but the second has not been used to develop arrays before. Once developed, either technique could be used to provide a realistic set of mission arrays, as will be described.*

The need for the treatment of uncertainty in this portion of the methodology is considered secondary to the treatment of the two-sided battle. Relegating uncertainty to a secondary role in target array generation procedures is motivated by the realization that the real uncertainties of the fire support mix problem lie in what happens to the array after it is developed. The detection, kill, and assessment processes all have major uncertainties more troublesome than the uncertainties in the fire support mission array. Thus, although uncertainty is a most desirable element for inclusion in the array generation procedure, it is not deemed mandatory whereas the ability to consider the two-sided battle is.

* The MAFAR mission generator, using the statistics produced by such alternatives, provides a technique to generate the specifics associated with air missions. If such a mission generator were expanded to include the characteristics of artillery and naval gunfire targets, then it would provide needed input to the mission allocation function. The feasibility of such expansion needs investigation but the probability appears good.

a. Computer-Aided War Gaming

Manual war games represent an excellent means for developing the target arrays, but they require excessive time and resources to produce realistic arrays. They are inherently two sided and they handle uncertainty, provided they are not used as they most frequently are today wherein the results of one pass through a game are used as the array for a whole spectrum of weapon mixes. Random events occur routinely in war games and are handled with Monte Carlo techniques. However, because most games are only played once, the results represent only a single realization of the random process. As a result, uncertainty is not adequately treated. Thus, although war games provide the greatest potential for realistic mission arrays, the time and costs involved generally preclude exercising the game an adequate number of times.

A partial solution to the problem is found in computer-aided war gaming. The objective of this technique is to reduce the human involvement, and the associated time delays, as much as possible by automating routine decision-making, calculations, and data processing. Most war games already make use of computers for bookkeeping purposes but decisions are made by players. Efforts have been made to increase the role of the computer. In fact, some of these newer models have been more properly termed "player-assisted simulations"¹² because many of the detailed decisions are made by the computer. STAG's LEGION is the prime example of this type of model.

Greater use of this approach offers potential for making war games a viable mechanism for generating realistic fire support mission arrays. The difficulties in further developing the computer-aided war gaming approach lie in deciding which decisions can be automated and which must be left to the players. Too much automation will degrade the purpose of the war game and too little will make it impractical for

array generation. One criticism the Army review committee had of LEGION was that much of the input needed for LEGION is nonexistent. This is a typical result when attempts are made to model decision-making because the troublesome parameters describing human behavior are generally left for someone to input without due consideration of their availability. Should greater use of computer aid for USMC war games be pursued, the objective should be to develop a procedure that reduces the number of players to as small a number as is consistent with realistic computer input requirements. The optimum mix of player and computer involvement will of course depend on the situation under analysis. Thus the study planner must address this issue with his own goals in mind.

In practice, the computer-aided war games would be used to enhance the realism of fire support mission arrays in the following way. A set of representative fire support weapon mixes would be selected to cover the spectrum of reasonable mix possibilities. Each of these would be played in a separate pass of the computer-aided war game. The results from all passes taken together would provide a spectrum of target/mission arrays in one-to-one correspondence with the spectrum of weapon mixes. The array spectrum would then be used in the remaining portions of the analysis to generate new arrays. Any new mix would be identified in terms of where it lies in the original spectrum of mixes to "interpolate" a new mission array for the new mix.

Naturally, the aim should be to keep the number of mixes in the original set comprising the spectrum to a minimum to reduce the number of war game runs. However, to be viable the spectrum must be representative. Thus, to use this approach, the analyst must devote considerable consideration to determining the number of mixes in the original spectrum by trading off running costs against completeness.

b. Two-Sided Computer Models

The use of two-sided conflict models provides a natural approach to solving the problem of one-sided mission arrays. Such models provide a means for simulating the reactions of opposing battlefield commanders to changes in weapon mix composition. There are several models in use today that attempt to model the two-sided conflict. However, of the models (as opposed to manual war games and computer-aided games) reviewed in this report only DYN-TACS (Ohio State), the Michigan study, and BALFRAM (SRI) are two sided. Other two-sided models are discussed in Ref. 12. They, as well as DYN-TACS, are designed around Army operations. In addition, DYN-TACS (described in detail in Appendix C) is a very detailed model that is better suited for analysis of individual weapon systems, particularly tanks, than it is for fire support weapon mix studies. The Michigan and BALFRAM models are not especially designed for fire support analysis, but their basic structures could combine to provide a useful tool for developing mission arrays. However, the more natural approach would be to use the proposed FSSAM model (Section II, above), which is planned to incorporate ideas from both these models. It should be developed as a part of the fire support hierarchy of models in any case. FSSAM provides a convenient mechanism for determining the first-order effects of changes in weapon mix composition on target arrays. First-order effects are the only ones of concern here because changes in the array that are of less significance are unlikely to affect the selection of an optimum mix.

FSSAM would be used in exactly the same way as the computer-aided war game approach described in Section II. FSSAM would have the advantage of being much easier to use than war games, but it would also have a problem that the war games can avoid. The aggregated inputs required for models like FSSAM are difficult to find or develop. In its primary function as described in Section II, FSSAM relies heavily on the

lower level, higher resolution models for input and the same reliance exists here also.

Both approaches, FSSAM and the computer war games, have difficult problems, and selecting between them deserves careful study. However, some type of dynamic modeling technique is required if the target array is to be responsive to the question of determining an optimum mix.

2. Fire Support Target/Mission List Generation

As described previously, the fire support target/mission list generation procedure is a means of translating the chronology of the actual positions of Red forces (the target array) into a list of target positions as viewed by the Blue fire controllers. The translation procedure involves the target acquisition and C³ functions.

a. Target Acquisition

The target acquisition submodel of the Mission Generation Element considers sensor and target combinations to determine if targets are detected, when, how accurately, and for how long. Many sensor models exist to do this on an individual target/sensor basis. However, one of the weaknesses in this area (as pointed out in Section II) is the inability to acquire whole units, like platoons. None of the studies reviewed address this aspect, but in a report¹⁷ describing the CRESS (Combined Reconnaissance, Surveillance, and SIGINT) model, SRI outlines an approach to the problem:

"The following method for producing estimates of the target to which a group of detected elements belong is based upon the use of Bayes' theorem. In using this method the probabilities that different kinds of enemy units may be operating in the area are determined by the intelligence officer using prior intelligence or his best estimate of the

situation. For each of the possible kinds of units the probability of detecting the particular elements actually sighted can be determined from the binomial distribution if the probability of sighting each of the individual elements is known. The latter probability can also be determined from a mathematical model of the sensor, a priori information, or from a subjective estimate. These probabilities can then be combined to give the probabilities that the actual unit sighted was one of each of the possible kinds of units."

The SRI report illustrates this method with an example of how it would be applied to a situation in which a tank platoon, a tank company, and a tank battalion are operating in the same areas. The example shows how this approach would model detection and the decision as to which of the three units had been detected.

Should the inclusion of the unit detection aspect be deemed an essential part of the fire support methodology (which depends on the problem being addressed), the SRI approach could be used. It would function best as a part of the supporting model for surveillance at the highest resolution level of the model hierarchy and would provide input to the fire mission list generation procedure.

The CRESS model itself could provide the entire supporting surveillance model. It is a comprehensive model that exhibits all the characteristics necessary for analysis of the fire support system. CRESS is an analytic model of the reconnaissance, surveillance, and signal intelligence functions in tactical warfare. It was developed to provide a model of reconnaissance and surveillance suitable for use in war gaming and systems analyses. It handles aerial and ground-based sensors of all kinds-- radar, IR, photo, lasers, TV, visual, intercept receivers, and passive night vision devices. The simulation of the operational use of any collection of sensors of these types produces (1) the target element detection

capability, (2) the location and location accuracy, and (3) the timeliness of generated reports--all as basic measures of performance of the systems.

One of the major weaknesses identified in Section II was the lack of a dynamic element in the modeling of target acquisition in current fire support studies. Surveillance systems are not allowed to react to a changing combat situation, and target acquisition capabilities are assumed to be independent of the weapons mix available for fire support. Both of these problems are direct results of the static nature of the approaches of these studies. If the remedies suggested in the previous section for mission array generation are implemented, the problem of static arrays will be alleviated. In turn, the effects of these two problems will be alleviated and the realism of target acquisition modeling will be enhanced. If the unified DYFSS approach were implemented, the entire problem would be solved for all practical purposes.

When the target acquisition model has been made dynamic in the sense just described, it can take on the convenient form used in many of the reviewed studies, namely, data specifying probabilities of detection and acquisition, and acquisition accuracy. The detailed modeling of sensors and targets will be carried out by the supporting surveillance model, e.g., CRESS. In target acquisition, as in so many other areas of the fire support system, the analyst must weigh the level of detail that should be included at each level of modeling. There may be times that it is necessary to include detailed target acquisition modeling at the key element level, e.g., when the difference in acquisition capability attributable to the weapons mixes is a key issue. However, in general, it is not necessary.

b. Command, Control, and Communications

The major weakness in the C^3 modeling area is the failure to take the accuracy and reliability of information into account. There are studies that handle C^3 directly, as was shown in Table 9; consequently, the techniques for doing so are available. The only thing required is to include a mechanism that accounts for the possibility of inaccuracies introduced into the mission list by the C^3 system. Although this represents a fairly simple modeling effort, developing the necessary input may be difficult.

As with target acquisition, many of the problems in the C^3 area will be alleviated or disappear, once the key element modeling becomes dynamic.

IV FIRE MISSION ALLOCATION AND FIRE SUPPORT SYSTEM EFFECTIVENESS

This section addresses both fire mission allocation and system effectiveness. Although these are two separate key elements of the fire support system, they are discussed together because they are usually modeled together. Most methodologies incorporating allocation and effectiveness do so in a single simulation.

A. Techniques in Use

1. Mission Allocation

Many of the reviewed studies do not actually address mission allocation. Those that do (there are seven) are listed in Table 13, along with a summary of each of their approaches. In the table the entries under the heading "Choice of Supporting Arm" indicate the rule, if any, the studies employ to allocate particular fire missions to one of the three supporting arms of air, naval gunfire, and artillery.

The criteria for selecting individual weapons for missions are listed in the succeeding columns, along with an indication of whether each study considered the remaining ammunition, range to the target, and higher priority targets in the choice of weapon. The final column indicates how target priorities were derived.

Perhaps, the most important point to be derived from Table 13 is that there is considerable consistency in the way that these diverse and independent studies handle mission allocation. This is a good indication that allocation is an area of the fire support system that is well understood, or not being questioned.

Table 13

SUMMARY OF MISSION ALLOCATION TECHNIQUES IN USE

Agency/ Study	Criteria for Choice Of Supporting Arm	Choice of Weapon						Target Priority
		Criteria			Ammo Checked	Range Checked	Preempt by High Priority Target	
		First	Second	Third				
CNA	Given weapons with equal quickness: Artillery over naval gun over air	Quickest kill	Ammo level	--	Yes	Yes	Yes	4 levels based on threat to Blue plans
Lockheed/ DEMS	Targets assigned by weapons not by supporting arm	Preference by target type	Smallest range	--	Yes	Yes	No	9 levels based on military judgment
Lockheed/ USMC	Artillery over naval gun, over air, given capability exists	Preference by target type	Smallest range	--	Yes	Yes	No	4 levels based on threat to Blue plans
STAG/ LEGION	Player choice	Player choice	--	--	Yes	Yes	Yes*	3 levels based on threat to Blue
NWL	Every mission assigned using military judgment	Military logic†	--	--	Yes	Yes	Not clear	5 levels based on threat to Blue plans
USACDC/ Legal Mix	Only artillery is at issue	Nonnuclear Ammo cost Nuclear Lowest yield required	Ammo weight Most remaining rounds	-- Most direct control	Yes	Yes	Yes	Algorithm for "military worth" used
WSEG	By judgment, given weapon capability (this is the study product)	Weight (surface) Cost (air)	Time to detect (surface) Total aircraft (air)	Cost (surface)	No	No	No	None

* In LEGION, player-ordered fire missions take precedence over automated fires.

[†] A very detailed weapon-target preference scheme is in Vol. 2 of Ref. 1.

The only novel technique found in the way the mission allocation element is modeled is in the Legal Mix study. It uses a concept called "military worth" in an attempt to simulate better the manner in which field commanders apply priorities to missions. Their basic concept is to assign a value of 1.0 to the least-valued mission and, to other missions, values above that, as estimated from a survey of experts. These values, plus estimated percentages of the time a particular target type would be engaged in specific activities, are used to generate a military worth value for a target engaged in those activities. The formula used for determining numerical values is:

$$W_t(a) = \bar{W}_t \frac{\bar{W}_{ta}}{A} \quad \text{where} \quad A = \sum_{a=1}^n \bar{W}_{ta} f_a$$

where

$W_t(a)$ = military worth of a target engaging in activity "a"

\bar{W}_t = mean relative worth of the target

\bar{W}_{ta} = mean relative worth of activity "a"

A = mean military worth of all activities

f_a = the fraction of time the target engages in activity "a".

Both the acquired target list and the actual target list are analyzed and given military worth values.

2. System Effectiveness

Probably the most consistently and uniformly modeled key element of the fire support system is the Fire Support System Effectiveness Element.

Most of the reviewed studies, aside from the purely analytical ones, put considerable effort in this area and develop extensive data.

There are three components to the Fire Support System Effectiveness Element: the missions, the weapons, and the damage determination procedure. The first two are inputs. The missions are provided by the target/mission list, and the weapons assigned to each mission are determined by the mission allocation algorithm. The third component, the damage model, combines the mission and weapons characteristics to assess the damage.

Table 14 addresses the first component, the missions, lists the studies that developed mission lists, and summarizes the makeup of the lists. The first set of columns gives the number of target types in the mission lists, e.g., three types of bridges for CNA. The succeeding columns give information about the mission parameters used. They are:

No. of Fire Mission Types--the number of fire missions, (destruction, neutralization, H&I, illumination, and so on) that are addressed.

Area versus Point--A "yes" indicates that a distinction was made as to whether the target was a point or an area target.

No. of Defeat Criteria--The total number of different criteria used within the mission list to specify the level of damage required to defeat targets.

No. of Personnel Target Postures--The number of descriptions used to designate personnel targets with respect to vulnerability.

Equipment and Personnel--A "yes" means that the study separated in some way the effects of damage to equipment of a system from the effects of injuries to the personnel who support it.

Moving Targets--A "yes" means that the study accounted for target movement in determining damage.

Table 14

SUMMARY OF TARGET CHARACTERISTICS IN CURRENT STUDIES

Agency/Study	Number of Target Types Considered															Characteristics							
	Airfield/Aircraft	Artillery	Bridge	Buildings	Fortifications	HQ	Personnel	Radar	SAM Site	Staging Areas	Supply Areas	Tanks	Vehicles	Others	Total	No. of Fire Mission Types	Area versus Point	No. of Defeat Criteria	Target Postures	Equipment and Personnel	Moving Targets	Neutralization	Target Shapes
CNA	2	3	3	2	4		10	1	1		2	3	3	8	42	1	Yes	2	4	Yes	No	Yes	Rectangular and circular
Lockheed/DEMS*	3	2	1		1		7	1			1	1	2	3	22	1	Yes	NG	12	No	Yes	Yes	Circular
Lockheed/USMC	3	1	1		1		9		1		1	1		1	19	3	Yes	6	3	No	Yes	Yes	Rectangular and circular
NWL	1	7	1	1	3	12	23	2	1	2	5	8	11	2	79	8	Yes	5	7	Yes	Yes	Yes	Rectangular
RAC†															11	NG	NG	NG	3	NG	Yes	Yes	NG
SRI/MAFAR	1	3	3	4	2		2	1	1		2	3	1	3	26	1	Yes	3	2	No	No	No	NG
USACDC/Legal Mix‡		X			X	X	X			X	X	X	X		NG	7	Yes	1	6	Yes	Yes	Yes	Circular
WSEG	4	5	1		3		7					8	16		44	1	Yes	2	3	No	No	No	Any§

NG = Not given.

*The only numbers available are for a "checkout run" of the DEMS model for a Korean environment (Ref. 18).

†The RAC study comprises several individual analyses. Target types are specified only in the most general terms, e.g., defended positions, terrain points, and artillery positions.

‡Targets are not given in a form suitable for a breakout by the number of each type, but there is a large number.

§The WSEG study models targets shapes by a grid system. By specifying which grid squares are covered by the target, any target shape with right-angle corners is possible.

Neutralization--A "yes" means that the study specifically addressed the subject of neutralization.

Target Shapes--The uniform target shapes assumed in the damage calculations.

Tables 15 through 17 address the second component (the weapons) of the system effectiveness element; they summarize the wide spectrum of weapon systems analyzed in the studies. The WSEG study provides data for a particularly large number of systems. (In contrast, the WSEG analysis is not too detailed.)

The third component of the system effectiveness element, the damage determination procedure, is the most important one from the methodological point of view. Table 18 summarizes how each of the reviewed studies handles damage determination. The second column entries specify how the three subelements of missions, weapons, and damage determination are combined to obtain measures of effectiveness. The entries in the columns under "Delivery Errors" indicate whether and how the studies incorporate delivery errors. "Target Location" indicates whether target location errors are included and have an effect on the damage determination.

Ballistic dispersion is generally handled by some form of the normal distribution. Some studies assume a circular normal that is equivalent to assuming that dispersion errors are the same in all directions about the target. For many systems this is far from true. The more detailed models account for direction-dependent errors by using a bivariate normal distribution for vertical and deflection errors. Only one technique, that used in the Michigan study, allows a means of modeling any correlation between successive hits. It is worth noting that the miss distances associated with successive hits will in general show high serial correlation.

Table 15

ARTILLERY SYSTEMS IN FIRE SUPPORT STUDIES

Agency/ Study	Number of Weapon Models Described													
	Mortars		Howitzers				Guns		Missiles					
	81mm	107mm	105mm	115mm	155mm	8"	155mm	175mm	Hon. John	Lance	MARS	Pershing	Sergeant	Others
CNA			1		1	1	1							
Lockheed/ DEMS		1			1	1	1	1	1			1	1	
Lockheed/ USMC*				1				1						3
NWL		1	2		3	1		1						
RAC			5		5	2		1	1	1	1			
USACDC/ Legal Mix			4		4	1			1	1	1	1	1	
WSEG	3	5	5		5	3	1	1	1	1	1			

* Since the major objective of the Lockheed/USMC study was to investigate various land weapon system design characteristics, general systems were used as the basic weapons.

Table 16

NAVAL GUN SYSTEMS IN FIRE SUPPORT STUDIES

Agency/ Study	Number of Weapon Models Described								
	5"/38	5"/54	5"/60	5"SSR*	6"/47	8"/55	16"/50	LFSW†	Others‡
CNA	1					1	1	1	
Lockheed/ USMC	1	1				1			2
NWL	1	2	1		2	3	1		
WSEG	1	3		1	2	3	1	1	

* SSR = Surface-to-surface rocket.

† LFSW = Landing Force Support Weapon.

‡ The Lockheed/USMC study considers versions of the Tartar and Terrier in a surface-to-surface role.

Table 17

AIRCRAFT IN FIRE SUPPORT STUDIES

Agency/ Study	Number of Aircraft Types Described			
	Attack	Fighter	Recce	Helos
CNA	2	0	0	0
Lockheed/DEMS	0	1	0	0
Lockheed/USMC	2	0	0	0
NWL	4	0	0	0
RAC	5	3	0	2
SRI/MAFAR	7	3	0	1
USACDC	0	0	0	1
WSEG	5	11	6	2

Table 18

SUMMARY OF DAMAGE DETERMINATION TECHNIQUES IN CURRENT STUDIES

Agency/Study	Method of Combining Targets and Weapons	Delivery Errors		Round Requirements*		Damage† Calculation (P_K)	Spotting Rounds	Reengage	Sub-targets
		Target Location	Dispersion	Point Target	Area Target				
CNA	Dne-sided, deterministic simulation	None	Bivariate normal uncorrelated hits	N_H/P_H	$\frac{\ln [1-K]}{\ln [1-E(C)]}$	Aggregate-Uses representative lethal areas	No	No	No
Lockheed/DEMS	One-sided, deterministic simulation	Yes	Circular normal uncorrelated hits	N_H/P_H	Detailed multiple weapons	$1-\exp \left[-n \frac{A_L}{A_T} \right]$	No	No	Yes
Lockheed/USMC‡	One-sided, deterministic simulation	None	Circular normal uncorrelated hits	$1/P_H$	$\frac{\ln [1-K]}{\ln [1-E(C)]}$	$1-\exp \left[-n \frac{A_L}{A_T} \right]$	No	Yes	NG
U. of Michigan§	Analytic, deterministic, two-sided, Lanchester model	None	Circular normal correlated hits	Detailed probability distributions	Detailed probability distributions	NG	No	Yes	Yes
NWL	One-sided, deterministic simulation	Yes■	Bivariate normal uncorrelated hits	N_H/P_H	$\frac{\ln [1-K]}{\ln [1-E(C)]}$	Detailed (Ref. 18)	Yes	Yes*	Yes
Ohio State/DYNTACS	Analytic, two-sided, stochastic model	Yes	Bivariate normal uncorrelated hits	Monte Carlo process used		Discrete effects simulated**	Yes	Yes	NG
RAC††	Qualitative/quantitative analysis	Yes	NG	NG	NG	NG	NG	Yes	NG
STAG/LEGIDN	Two-sided, stochastic, computer-aided war game	Yes	NG	NG	NG	A_L/A_E (for a single hit)	NG	Yes	NG
USACDC/Legal Mix	One-sided, stochastic simulation	Yes	Circular normal uncorrelated hits	$1/P_H$	Detailed iterative solution	A_L/A_E (for a single hit)	Yes	Yes	Yes
WSEG	Qualitative/quantitative analysis	None	Bivariate normal uncorrelated hits	Done by round-by-round iteration	Done by round-by-round iteration	$1-D \cdot 2^n$	No	No	Yes

NG = Not given.

* N_H = number of hits required; P_H = hit probability of single round or sortie, K = level of destruction required, $E(C)$ = expected % casualties from one round or sortie.

† P_K = Probability target killed, A_L = lethal area, A_T = target area, A_E = "area of effect" for warhead (area of fire concentration), n = number of hits.

‡ Under "Round Requirements, Area Target", for air, a table is given without detail; for missiles, used table from Ref. 18.

§ Michigan's model relies on Lanchester attrition rates which are the reciprocals of the expected times to defeat which in turn depend on the rate of fire and N_H . Equations are developed for several fire doctrines and target types.

■ NWL's program allows a target to be erroneously located, but this does not affect the rounds fired.

* NWL study used a war game to generate the target list. If a target survives (Monte Carlo) in the war game, it reappears in the simulation.

** Conditional probabilities of outcomes given a hit are computed for weapon-target combinations using regression and then a Monte Carlo process is used.

†† RAC did not report on the bulk of the techniques they used.

The manner of calculating round requirements in the various studies demonstrates significant consistency. Most use the geometric distribution approach to determining round requirements for point targets. It yields the N_H/P_H value for the expected number of rounds required that appears frequently in the table. The Michigan and Ohio State studies use more complex models in attempts to handle the underlying stochastic nature of the process and the varying fire doctrines in greater detail. The WSEG approach is to evaluate target damage on a round-by-round basis, which results in similar results to those obtained by using the N_H/P_H approach. Area targets are handled differently, most frequently in terms of a required level of destruction, K . The equation appearing frequently under the "Area Target" heading is derived by assuming that the expected damage level of N_R rounds, each having a probability of hitting the target of P_H , against a target of area A_T , and lethal area A_L is given by:

$$K = 1 - \exp \left[\frac{P_H N_R A_L}{A_T} \right] .$$

Letting $E\{C\}$ be the expected damage level for one round, this equation is solved for N_R to give

$$N_R = \frac{\ln [1 - K]}{\ln [1 - E(C)]} .$$

DEMS, Legal Mix, and WSEG use more complicated approaches to simulate the round-by-round or sortie-by-sortie destruction of an area target.

Entries in the "Damage Calculation" column show that the two Lockheed studies use a form of the above expression for the calculation of the level or fraction of damage suffered by a target, i.e., P_k . CNA, LEGION, Legal Mix, and WSEG use even simpler approaches. CNA's aggregate

approach uses representative lethal areas for whole classes of targets. LEGION and Legal Mix assume that the level of damage is equal to the ratio of the lethal area of the round against the target, A_L , to the area in which fire is concentrated, A_E . The WSEG approach assumes that the probability of kill given a single hit is 0.8 for every type of target and every type of ordnance. The NWL and Ohio State (DYNTACS) studies use more detailed approaches. NWL carries out complex calculations for each target and weapon system using the "Simplified Weapons Evaluation Model" developed by RAND and described in Ref. 19. Ohio State uses regression analysis to fit curves for probabilities of kill given a hit as a function of range and errors.

The "Spotting Rounds" entries indicate whether such rounds were added to the number of rounds required. The entries in the "Reengage" column indicate whether a missed target could be taken under attack a second time. There are two ways a target can be missed: it may have moved since the original fire ordered was sent or the round may simply miss the target. In those studies for which a "No" appears, it is assumed that if "the required number of rounds" is fired, the target dies and therefore never occurs on the mission list again. This assumption is apparently also made for those studies with both a "Yes" under "Reengage" and a "deterministic" under "Method of Combining Targets and Weapons." These studies do not have a means for specifying whether a mission is or is not successful in terms of the round missing or hitting the target. Thus the studies with deterministic simulations and a "Yes" under "Reengage" only account for targets that are missed because they move. The only studies that address the need to reengage for any reason are DYNTACS, Legal Mix, and LEGION.

Although there is a "Yes" under "Reengage" for the NWL study, it should be pointed out that whether a target does or does not reappear is determined in the NWL war games carried out preliminary to mix evaluation.

The characteristics of the particular weapon mix under analysis do not affect target reappearance.

The "Subtarget" entries indicate whether the studies provide for breaking up complex targets to assess damage on a subtarget basis before assessing the effects of a hit on the complete target.

Several of the studies address the subject of neutralization. Of those studies that mention suppression, most equate it with or consider it as a part of neutralization. Table 19 summarizes the way the studies approach neutralization and suppression. The CNA report²⁰ has an especially good discussion of neutralization and presents historical data in several forms. It is discussed in more detail in the CNA write-up in Appendix C of this report. None of the studies address the subtleties of suppression as opposed to neutralization. The closest is probably DYN-TACS. It considers the time a system is out of action, which is more closely related to suppression fires than to the more destruction-oriented neutralization fires.

A related subject is attrition/vulnerability. The manner in which the reviewed studies treated these subjects is contained in the appropriate summary analyses in Appendix C, generally under the heading "Weapon Survivability."

3. Support Models

Figure 5, presented early in Part II, shows five models supporting the System Effectiveness Key Element Model. They are the Weapon Effects Model, the Intelligence Model, the Logistics Model, the C³ Model, and the Mobility Model. In the existing studies most of these supporting functions are modeled directly as a part of the effectiveness simulation; thus there are no supporting models per se. However, there are some exceptions to this observation. The weapon effects support model used by NWL is one such exception.

Table 19

NEUTRALIZATION/SUPPRESSION IN FIRE SUPPORT STUDIES

Agency/Study	Method of Handling Neutralization/Suppression
CNA	Naval gunfire and air only: the number of rounds required to neutralize a 7-km ² area for landing as a function of the depth of the landing zone. The data are based on World War II amphibious assault data.
Lockheed/DEMS	Number of rounds fired is the number of rounds required (an undefined input) divided by the probability of hitting the target area.
Lockheed/USMC	A predetermined number of rounds on target per unit area is used.
NWL	Study addresses preparation fire in terms of predetermined amounts of ordnance using 100m ² area for naval gunfire, dispensers of Rockeye for air, and rounds of 105mm HE as norms.
RAC	Study gives curves of target area neutralized by one battalion and one battery of 155mm and 8-inch howitzers. Data based on World War II and Korean data.
USACDC/Legal Mix	A predetermined number of artillery rounds is used per unit area.
Ohio State U./DYNTACS	Neutralization is modeled by assuming that a system is out of action for a time specified by input if a fire impacts sufficiently close to it.

a. Weapons Effects

As mentioned previously, NWL uses a detailed model developed by RAND for damage assessment.¹⁹ This model was exercised independent of the main stream of NWL's analysis to develop round requirement curves versus range to the target. Hundreds of these curves were developed for many combinations of targets and weapons.

Unlike NWL, most studies used a fairly simple approach to weapons effects, as may be seen in Table 18.

b. Intelligence

The primary function of the intelligence model supporting the weapons effectiveness key element is to simulate the damage assessment capability of the intelligence system. It simulates the system's ability to determine if, when, and to what extent a target is damaged. This information is communicated via the C³ system to determine the need for scheduling additional fires, as necessary. Thus the Intelligence Model comprises the functions of the previously described Target Acquisition Model (Section III-C-2-a) and the sensor's ability to assess damage.

Those studies that have a "Yes" under "Reengage" in Table 18 demonstrate a realization of the problem of damage assessment but only two of them, DYN TACS and LEGION, have the capability to address it directly. The others assumed that the intelligence is perfect. Even for those two studies that appear to have the capability, the approaches are difficult to assess. The documentation available for review does not detail how they handle the intelligence function.

The player/machine interactive character of LEGION provides a natural method of simulating the flow of intelligence throughout a battle. DYN TAC's ability to adapt to a changing battle situation also provides this

capability. In both these models the intelligence function is a continuous part of the evaluation procedure. Information from observers and sensors is monitored by the command and control structure to determine the state of all targets and missions.

c. Logistics

Like intelligence, logistics is generally handled as part of a simulation. Table 20 summarizes how the reviewed studies considered logistics. Only three of them treated the logistics system in anything but an elementary manner. Most studies consider ammunition supply, and about half of them consider resupply in at least elementary terms. The Lockheed/USMC study team devoted a special supporting analysis to the logistic feasibility of all systems to determine their impact on the requirements of land transport, POL, and sea lift. The results of this investigation affected the input of fire capabilities to the simulation in some cases and caused limitations on the acceptability of simulation results in others.

MAFAR considered two aspects of logistics: maintenance and resupply. Maintenance is included in the modeling of the capability of the aircraft in terms of probability of maintenance required and mean maintenance time. Supply requirements are reflected in the output of the simulation. Ordnance and POL requirements are measured in terms of utilization per day and cumulative utilization.

LEGION is the only model to address the logistics system directly. One set of submodels in LEGION is the Administrative Support Submodels. They perform the logistic functions of LEGION by simulating the flow of personnel replacements and major equipment within the division area, in addition to the resupply of consumable items (Classes III and V). These functions concern parameters such as distance and terrain and the operations of supplying a unit under fire and losing supplies in

Table 20

SUMMARY OF LOGISTIC MODELING TECHNIQUES IN STUDIES REVIEWED

Agency/ Study	Logistics System	Ammunition Supply	Resupply
CNA	Considered in elementary terms for naval gunfire	Considered for each weapon independent of model	Considered for naval gunfire only
Lockheed/DEMS	Considered in elementary terms	Input to simulation	Input to simulation
Lockheed/USMC	Received considerable attention in separate analyses for each weapon	Input to simulation	Not part of simulation but affected initial supply values input
U. of Michigan	Not considered	Unconstrained supply	Assumed available
NWL	Considered in elementary terms	Input to simulation	Assumed available
Ohio State U./ DYNTACS	Considered in elementary terms	Input to simulation	No resupply available
RAC	Not considered	Not considered	Not considered
STAG/LEGION	Detailed modeling (see text)	Modeled	Modeled
USACDC/Legal Mix	Considered in elementary terms	Input to simulation	Input to simulation
WSEG	Not considered	Not considered	Not considered
SRI/MAFAR	Considered in terms of maintenance and supply. Maintenance modeled in capability of aircraft.	Output of simulation	Assumed available

transit. Players may introduce priorities of resupply and the use of air delivery for long distance resupply.

d. Command, Control, and Communications

The C³ support model of the Fire Support System Effectiveness Element is the same as that for the Mission Generation Element. As a result, the earlier comments on C³ modeling in Mission Generation, as summarized in Table 9, apply to System Effectiveness as well.

e. Mobility

Like other supporting models, the mobility aspect of fire support system effectiveness was handled in widely varying ways. Much of this variance is due to the different emphasis and objectives of the studies. It is not surprising, for instance, that mobility is not considered at all in the CNA study, which is an analysis of naval gunfire systems requirements, and that DYN TACS, which is a dynamic model of tank combat, has very detailed models of mobility of tanks.

Two aspects of fire support effectiveness are affected by the mobility of the fire support system. One is the ability to respond to fire support requests because of the location of weapons and is particularly relevant to air fire support and the location of air bases--both land based and sea based. The second aspect is the ability, particularly with respect to land weapon systems, to support mobile troops. As troops have become increasingly mobile because of the use of helicopters, the need for mobile fire support has increased. In the words of the Legal Mix Study,

"History has shown that mobility is a primary factor in attaining success in battle.... Combat support units must have mobility

equal to that of the combat elements they support; however, this does not imply that the support artillery be required to keep pace, step by step, with the supported force. Field artillery units must be capable of moving over the terrain with a high assurance that they can maintain continuous support to the maneuver force."

The study further points out other factors that influence mobility:

"Field artillery has a measure of mobility in its range. Its ability to keep up with the fight is aided by the tactic of displacement by echelon...."

A brief description of the various methods of treating mobility is given in Table 21.

Several of the studies treated mobility, (i.e., the deployment, movement, and redeployment of fire support units) during the threat analysis or development of target lists. The resulting placements and movements subsequently were fixed inputs to a simulation model of effectiveness in terms of location coordinates and/or range to target information. Typical of this procedure is the NWL study in which the supporting arms movements used in the model are derived directly from the general movements of supporting arms in the manual play of the war game.

Those studies that were mainly combat models rather than fire support studies, e.g., DYTACS and LEGION, paid particular attention to mobility of the units within the simulation model of combat. The most detailed mobility analysis was contained in the DYTACS study. In this study mobility is first treated as part of the set of Design Models that supply vehicle performance inputs to DYTACS. The Mobility Models are at a high level of detail and describe:

Table 21

SUMMARY OF THE TREATMENT OF MOBILITY IN THE REVIEWED STUDIES

Agency/Study	Treatment of Mobility
Lockheed/DEMS	Considered through analysis done in developing target lists, disposition of forces, and acquisition rates prior to use of the model.
Lockheed/USMC	Considered through analysis done in developing target lists and disposition of forces prior to use of the model. The aspect of mobility is a qualitative MOE that is considered before study recommendations are given on preferred weapon systems/mixes (particularly whether a system was helicopter-transportable).
U. of Michigan	Mobility of combat units is considered in the differential equations in restrictive sense by allowing attrition rates to vary with range.
NWL	Movements of supporting arms firing units are simulated by input events that change their location. Units are deactivated for intervals of time, depending on the distance and method to be moved. Movements correspond to general movements in the manual play of the war game.
Ohio State U./DYNTACS	Detailed models of movement controller and movement are given for grouping of combat elements, called maneuver units. Maneuver units can be classified as supporting fire units containing antitank, crew-served weapons and/or indirect fire guided missiles. Major fire support is given by indirect fire ballistic weapons that are assumed to be stationary. Study also contains a higher resolution model of mobility as a function of tank design characteristics.
RAC	Mobility is a key issue in all of the analyses conducted. However, it is not clear how it is modeled, if modeled at all. (Analyses of different phases of the battle are often of a qualitative nature.)
STAG/LEGION	Movement of fire support units is simulated within the model. It is assumed that movement rates are given for the terrain, which is defined in terms of elevation and the presence or absence of various natural obstacles. For example, a direct support unit can move to a different firing position when the distance between it and its close-combat unit becomes too great.
USACDC/LEGAL MIX IV	Deployment, movement, and redeployment within the model are "based on a preliminary analyses of the threat and the dynamics of the tactical situation." In addition, a detailed qualitative analysis of mobility aspects of weapon systems was conducted, leading to a ranking of candidate systems in terms of cross-country mobility, air mobility, and water-crossing mobility.
WSEG	It is assumed that optimal mobility conditions exist in the process of weapon system selection.

- Power plant limiting speed as a function of slope, vehicle weight, and power plant characteristics.
- Limiting speed in soft soil.
- Limiting speed over rough cross-country terrain.

DYNTACS itself models movement of maneuver units using detailed inputs of terrain characteristics like the resistive force coefficient and vehicle characteristics like air rolling resistance and pitch diameter of drive socket.

The bulk of fire support within DYNTACS, however, is assumed to be stationary.

Finally, the Lockheed/USMC and Legal Mix studies recognize the importance of mobility by including a qualitative mobility consideration as part of the analysis of preferred weapon systems/mixes. For example, in the Legal Mix Study an additional qualitative analysis of the mobility of each weapon system in the particular environment under consideration led to a ranking of candidate weapon systems. This information is considered in the final selection process of a preferred mix.

B. Evaluation of Strengths and Weaknesses

As mentioned above, in general, the Mission Allocation and Weapons Effectiveness Key Elements are well handled in the current studies that address them; they are well understood and well modeled. Some of the supporting models at the high resolution end (lowest level) of the fire support model hierarchy are weak in certain areas. However, it is a matter of the particular issues at hand in a study that determines whether detailed modeling is required in these areas. This is a question that must be decided by the analyst in terms of the objectives of his specific study.

1. Mission Allocation

In general, mission allocation is adequately treated in the fire support mix studies. The models simply reflect the way the analyst sees the decision process, and they are fairly consistent from study to study (see Table 13). One area of concern is the fact that there are some differences among the studies about the criteria used in selecting a supporting arm and an individual weapon system. Some studies consider costs and others do not; some consider the timeliness of the kill and others do not. For study purposes, it would be advantageous to have a consistent set of criteria based on operational doctrine and experience. The analyst must be careful to use such criteria rather than ones that are only analytically appealing. For example, although costs of the rounds expended is an important criterion in a planning study, it is not likely to be a major concern to the officer allocating weapons in actual battle.

Related to realistic allocation criteria is a subject that does not represent an actual weakness in current fire support methodologies but will be one if current techniques are applied to future methodologies. Current techniques would be inappropriate because future fire support systems will employ a considerably greater level of automation than is found in the current system.* Mission allocation is a likely candidate for automation. A computer can account more quickly for ammunition stockage, intelligence information, prior allocations, and plans for future operations than a man. Automation could provide an optimized priority of weapon systems for each mission as a vital part of the information used by the officer performing the allocation process. Should

* One pertinent example is the Marine Corps on-going effort in the Marine Integrated Fire and Air Support System (MIFASS).

such a procedure be implemented, criteria for allocation would be standardized, which would actually ease the problem of modeling allocation in fire support studies. Thus, the advent of an automated approach to allocation should portend little in terms of modeling problems, but it will require new mission allocation modeling techniques.

2. System Effectiveness

Several simulations address the interactions of mission lists, weapons, and damage determination. How they do this is described above in subsection A; they usually do it well. The weapons effects area is particularly strong, a prime example being the NWL study. Given that the information used and the data developed by NWL for rounds required are validated, they provide a valuable data bank for future studies.

The major weaknesses in this area are in the supporting models. Modeling of the intelligence function is a particularly weak point, even though intelligence is an important part of the fire support system. To ignore the effects of the intelligence system's capability to assess damage represents a major assumption. Yet most studies do ignore this capability. Only LEGION and DYN-TACS show any apparent strength in addressing this aspect of the intelligence function. Ignoring it is equivalent to assuming that damage assessment is perfect. This assumption penalizes direct fire systems but not indirect fire systems since damage assessment for indirect fire requires independent sensors or observers. As a result damage assessment is more complex, costly, and frequently less reliable than it is with direct observation.

It has been pointed out that many studies assume that if the "required number of rounds" are fired at the target, the target is killed. This can lead to underestimating the number of missions that must be performed. As an example, a measure that frequently determines the number

of rounds required to "kill" a point target (N_R) is an average value given by

$$N_R = N_H / P_H ,$$

where P_H is the probability of hitting the target with a single round and N_H is the number of hits required to attain a required level of damage. Use of this formula can lead to underestimating round requirements. If this formula is followed rigidly and P_H is less than 0.2, as it usually is, it can be shown that the chances of not killing the target (i.e., not reaching the level of damage specified) are between 33 and 37 percent when $N_H = 1$. Thus, in such a situation one-third of the time the required level of damage is not attained. In some studies, such as the NWL study, the tactics used in target attack may lead to greater actual ordnance expenditure than the average value.

Related to the above is the fact that required level of damage is also random in nature. In some situations a single hit in the right place can completely disable a system; in others, many hits in the wrong places will allow the system to function effectively. Thus the stochastic element pervades the effectiveness element of the fire support system. Its absence in the weapon effectiveness assessment can represent a significant weakness, although it may be expensive to supply, that can result in underestimating total ammunition requirements.

In the majority of the reviewed analyses of fire support systems, logistics is generally treated as a constraint in a simplistic manner. An adequate logistic system can be designed to support any reasonable fire support system, and in this sense the logistic system should not be considered as a constraint. More realistic constraints on fire support system mixes are total personnel, equipment, and dollars for the entire Landing Force or Amphibious Task Force. The use of these totals as constraints

permits analysis of both combined costs of the operational fire support system and its effects on the logistic support system, and the trade-offs that may be achieved between the two.

The entire logistics system plays an important part in a fire support mix study. The significance of the logistics of fire support systems costs and the importance of including differing logistic requirements for alternative mixes are readily apparent from several general facts. For example, approximately 83 percent of the personnel strength of the operating squadrons of the VF/VA Marine Air Group (MAG) is devoted to logistic support. In addition, a major portion of the operation of the Marine Air Base Squadron and the Headquarters and Maintenance Squadron of the MAG are for logistic support. Further logistic support is provided by the Marine Wing Service Group and the Force Service Regiment. A similar chain of requirements and costs can be traced for surface fire support systems. Another example of logistic costs stems from analysis of personnel occupational fields in the Marine Division. Approximately 30 percent of the total personnel of the Division are in the logistic field.

The studies that display a special strength in logistics analysis are the Lockheed/USMC, the SRI/MAFAR, and the STAG/LEGION studies.

The strengths and weaknesses of C^3 modeling for weapons effectiveness are the same as those discussed in Section III-B-2-b for Mission Generation.

Because of the wide variance in methodologies used to treat the effect of mobility on system effectiveness, strengths and weaknesses must refer to a particular study or group of studies.

Studies that consider the deployment, movement, and redeployment of fire support prior to the use of the model encounter the problems that have been mentioned in the generation of targets. In effect, they assume that a change in weapon system characteristics and/or weapon mix will not

influence the dynamics of the battle, i.e., that the particular positions of fire support units in the threat analysis will be fixed for all weapon mixes.

Some studies recognize this problem and perform an additional qualitative analysis of mobility before a preferred mix is suggested. The Legal Mix IV study performs a thorough qualitative analysis of mobility that results in an ordinal ranking of candidate systems. But the subjective nature of both the development of such a ranking and the subsequent use of the ranking are troublesome. The Honig study of selected army models considers this problem:¹²

"Now we must ask ourselves, 'What does the state of the art of modeling tell us about the dependence, quantitatively, of casualties and rate of advance on these five functions of combat?' Sadly, the answer is very little for firepower and ammunition supply and nothing of note about mobility, intelligence, command control communications and the bulk of the logistic function. It is not that there isn't a good qualitative appreciation of these functions.... But for analytical purposes we need precise formulae which show the impact of these functions on the combat outcome."

The Honig study notes a particular lack of modeling for air mobility. Although the comment refers mainly to ground combat units, the same can be said of fire support units.

DYNTACS has perhaps the strongest treatment of mobility. It models maneuver and firepower interactively, representing the dynamic decision process of the maneuver unit leader. Terrain and vehicle mobility characteristics are modeled at a high resolution, and it is backed by higher resolution Design Models of mobility. The weaknesses of DYNTACS have been mentioned previously: it is specifically designed as a tank combat model and is particularly cumbersome to use because it requires large amounts of inputs and computer time.

C. Alternatives

1. Mission Allocation

The only alternative suggested to techniques in current use for modeling mission allocation is more of an improvement than an alternative, that is, to develop a better set of criteria for weapon selection. As mentioned earlier, some of the criteria in use do not appear to represent adequately the criteria in use in the battlefield. A study of how fire control officers select weapons for particular targets is needed to supply realistic criteria for modeling purposes. Whether these criteria turn out to produce the best allocations is not particularly germane as long as they realistically model the procedure. On the other hand, in anticipation of increased automation in the mission allocation process, a model designed to determine the best allocation criteria would also be useful as a part of an independent analysis. Such a model will be necessary in any event to determine how automation can be most usefully implemented.

2. System Effectiveness

Many of the simulations employed in fire support studies are detailed and cumbersome to use. An alternative to such detailed models is the aggregated approach proposed earlier in this study. Under this concept, simulations at the key element level are aggregated compared with many simulations in use today. They would rely heavily on a strong set of supporting models for weapons effects, intelligence, logistics, and C³. Thus the bulk of this discussion is devoted to explaining the alternatives and improvements that show potential in these supporting areas. The overall approach alternatives, including system effectiveness, are discussed above in Section II.

3. Weapons Effects

An example of how the profitable use of supporting models can be achieved is the NWL approach to weapons effects as described above. NWL used a detailed model of weapons effects to generate aggregate data for use in their fire support simulation. The NWL data are directly applicable to many fire support studies. If more data are required, the RAND model used to develop the NWL data is readily available and adaptable to most of the weapon systems of interest in fire support analysis.

One of the identified weaknesses prevailing in current weapons effects models is the problem of using fixed values for the number of rounds required and then assuming that firing that number always kills the target. This assumption can lead to underestimating ammunition requirements. The alternatives are straightforward but not necessarily implemented. One is to include the random element in the simulation. This approach generally entails a considerable increase in the expense of running time of the simulation. A second alternative is to allow a fraction of the targets to reappear automatically to simulate their being missed the first time they are fired at. Should this approach be implemented, it would be handled primarily in the support model for weapons effects because it will be necessary to develop aggregate survival fractions for the Key Element Model from consideration of many individual weapon/target engagements.

4. Intelligence

The use of a detailed model of the intelligence function would alleviate the problem of the inadequacy of damage assessment models. Since much of what goes on in the intelligence function is subjective, the modeling should emphasize the behavior of the person assimilating

the information. Some aspects of the Bayesian approach to the unit detection function, as described above, in Section III-B-2-a, relate directly to the damage assessment function. Both functions often entail melding diverse pieces of information to reach a decision.

Another alternative is an empirical one aimed at identifying estimates of the probability of correctly assessing damage information. The objective would be to develop such estimates for various combinations of sensors and targets. The difficulty with this approach, as with many modeling techniques, is being certain that appropriate data are available or can be derived for the model.

5. Logistics

As noted earlier, the reviewed studies often treat the logistic systems as a constraint when the costs of the logistics system are the actual constraint. Logistics costs comprise the logistic requirements, e.g., personnel, equipment, and supply consumption generated within the fire support system and the costs of that portion of the Landing Force logistic system that is required to support the fire support system. These logistic costs within and external to the fire support system can and should be determined for each alternative mix of weapons. Expansion of fire support analysis to include logistical effects in greater detail would vastly improve the capability to conduct cost/effectiveness analysis of alternative fire support mixes. For systems of equal effectiveness there would be a much wider and more realistic basis for using cost criteria in selecting the preferred system. Also, any differences in personnel, equipment, and dollar costs in the logistic system could be applied by feedback processes to the less costly fire support systems to increase their effectiveness and to provide new comparative bases for selecting the preferred system. At a higher level of aggregation, analyses could include evaluation of the fire support system against other systems

of the Landing Force to determine the slice of the total Landing Force resources that may be accorded the fire support system in combination with its logistic support requirement.

More specific information on the magnitude and complexity of the logistic requirements and costs to support fire support systems is detailed in a number of SRI studies. Adaptation and integration of the models in these studies can provide the capability to analyze the major portion of the logistic costs of alternative fire support systems. In addition to the MAFAR study¹⁰ there are other SRI studies that are fundamentally logistic studies and model developments. They have modeled many aspects of the logistics systems in detail, such as requirements for: ammunition, transportation (air and ground), materiel handling, fuel storage, personnel, aircraft facilities, and amphibious lift. These requirements are all addressed and the models used are described in Refs. 21 through 26.

These models would require some modifications to eliminate details beyond the scope of a given study and additions to establish their inter-relating effects. The effort could be extensive and the resulting total computer program might be complex. However, such an approach is a valid alternative to previous treatments of logistic costs in the analyses of fire support systems and could provide the type of supporting model envisioned for the Fire Support System Effectiveness Key Element of the methodology.

6. Command, Control, and Communications

The C³ modeling problem for weapon system effectiveness is the same as that for mission generation. So are the alternatives, which primarily address methods for including message accuracy in the model. They are discussed above in Section III-B-2-b.

7. Mobility

As pointed out previously, the most serious weakness in the treatment of mobility (aside from not treating it at all) is the failure to relate it to a changing weapon mix composition. The remedy is to make certain that changes in weapon system characteristics and weapon mix influence the dynamics of the battle. In particular, the impact of a changing weapons picture on the position of fire support units must be considered. This is consistent with the overall approach proposed at the beginning of this section. Incorporation of mobility into the aggregated model of FSSAM and the dynamic model DYFSS is a natural result of the philosophy underlying them. In addition, models designed to provide the details of movement rates and of position changes for particular systems can be used when necessary in much the same way that the Ohio State study uses its Design Models and DYN-TACS.

V FIRE SUPPORT SYSTEM MIX SELECTION

A. Techniques in Use

Only three of the reviewed studies were conducted for the purpose of determining an optimum mix of air, artillery, and naval gun weapon systems and resulted in preferred mixes of the three supporting arms. These studies, as described earlier, are the Lockheed/USMC effort of 1961, the USMC Fire Support Requirements Study of 1963, and the NWL study of 1972. The Lockheed/USMC effort, although a true mix study, was primarily interested in determining the best design characteristics for land-based SSM systems and only secondarily interested in noting trends in the best fire support mix composition. In addition, only a few variations in mix composition were considered in the analysis. The USMC study of 1963, also a true mix study, did not provide for full range variations in air and naval gunfire, but did for artillery. The NWL study of 1972 provides for preferred mixes of all three supporting arms, based on analysis of variations in each arm.

The remaining studies reviewed were either model developments that stop at the point just prior to an optimum mix selection model or studies concerned with optimizing within a particular supporting arm rather than over all three supporting arms. The latter studies, however, and some of the model development studies did cope with difficulties similar to those of the overall mix studies or to any study that attempts to perform a cost/effectiveness analysis.

To perform such an analysis, the following are necessary:

- Measures of effectiveness (MOEs).
- Cost measures.

- A methodology for combining the above two measures to perform comparisons.
- A criterion to make a selection.

The difficulties of performing a cost/effectiveness analysis in a fire support problem begin with determining an appropriate measure of effectiveness. Even at this level, there is no consensus. The MOEs considered in the various reviewed studies are shown in Table 22. Although many of the measures are related, it is clear that each study measured the effectiveness of fire support in different terms.

The use of a "military worth" index by the Legal Mix IV study was an attempt to improve on previously used MOEs--in particular, the measures on missions performed. The rationale for its derivation was that, even though targets and missions were generally processed according to a priority system in previous studies, all became weighted equally when included in a targets-killed or missions-performed statistic.

The military worth index MOE is the sum over all targets of the product of the probability that a unit will break (a function of the percent of damage inflicted) and the actual military worth of the target. Each target has associated with it an estimated military worth that is used in mission allocation and an actual military worth that is used to determine actual effectiveness. The latter is more germane to the mix selection element than the former. The approach Legal Mix uses to derive military worth values is described in Appendix C and above in Section IV-A-1 in connection with mission allocation techniques.

There is a consensus that cost is a primary measure of effort, but additional measures, such as weight of ammunition expended, were considered in certain studies. Even with the cost measure there was not a consistent definition of what costs were relevant. Both total peacetime cost and ammunition costs were considered in the studies, either sepa-

Table 22

MEASURES OF EFFECTIVENESS AND MEASURES OF EFFORT USED IN FIRE SUPPORT STUDIES

Agency/Study	Measures of Effectiveness																Measures of Effort									
	Targets Assigned	Targets Attacked	Red Personnel Casualties	Red Ton Materiel Casualties	Weapons Attacked	Live Target Time	Target Firing Time	Lost Targets	Vehicles Defeated	Military Worth	Targets Killed	Missions Performed	Enemy Force Firepower Losses	Friendly Force Casualties	Min. Required Personnel Cost	Blue Loss (\$)	Tons Ammo Expended	Fire Support Utilization	Total Peacetime Cost	Ammo Costs ■	Mission and Nonmission Time	No. of Engagements by Firing Unit	Weight over the Beach	Ammo Replenishment Time		
CNA						X	X	X							X											
Lockheed/DEMS	X	X	X	X	X										X	X	X									
Lockheed/USMC										X	X ⁺			X	X [*]							X ⁺				
NWL					X					X ⁺	X ⁺	X	X		X		X			X	X [§]		X			
USACDC/Legal Mix IV			X				X	X	X								X	X	X							

* Cost can be either total annual cost to provide fire support capability or expended ammunition cost only depending on phase of analysis.

† Can be either total weight of equipment and ammunition or of ammunition only, depending on phase of analysis.

‡ These are divided into two time periods: from the beginning of the game to 1200 on D-Day, and from 1201 on D-Day to the end of the game.

§ These are listed as outputs but are not used in cost/effectiveness analysis.

■ Ammunition costs are indicated separately only when the cost column is not checked.

rately or summed into a total cost figure. Other differences noted concerned life cycle costs versus program costs, the use of a discount rate and/or inflation rate, and the use of a terminal value associated with the systems. A discussion of these concepts and their use in the studies appears in Section VI.

The last requirement for performing the cost/effectiveness analysis is the methodology for applying measures of effectiveness and of effort to compare alternative systems/mixes.

The following is a discussion of the technique used by each study that attempted to relate effects and costs for comparison purposes.

1. Center for Naval Analyses Study

This was not a mix study but a naval gunfire support study. No particular ship was selected as "optimum," but cost and effectiveness measures were considered in reaching some general conclusions.

As shown in Table 22, the results of the study are given primarily in terms of three MOEs.

- Live target time--Time between target occurrence and the last impacted fire.
- Target firing time--Time between target occurrence and impact of first fire.
- Lost targets--Number of targets that disappear before being engaged.

A higher level measure of effectiveness transforms the above three into an "equivalent notional cruiser." "The notional cruiser, for a given scenario and special situation, is defined by considering the

changes in the measures of effectiveness that result when 3 cruisers are added to the Base Force and then dividing the changed measures by 3."²⁷

The rationale for performing this additional operation on the basic MOEs is given as follows:

"When comparing forces or discussing the effect of variant assumptions it will sometimes prove convenient to have a single (and slightly more intuitive) measure of effectiveness than can be provided by the simultaneous consideration of lost targets, target firing time, etc. This simplification can be accomplished by the introduction of the 'equivalent notional cruiser'."²⁷

Once the average change in the basic MOEs is determined for an equivalent notional cruiser, any changes in the measures due to additional cruisers can be expressed in terms of equivalent notional cruisers gained.

Cost is considered by running equal cost simulations at seven different levels of cost. General conclusions are then made based on the cost and effectiveness data.

2. Lockheed/DEMS

Although DEMS was only a model development effort, a list of measures for comparison was given that combined effects and efforts into ratios. No criterion for actual selection was given, but the following were assumed to be the relevant measures for comparison:

- Cost/target assigned
- Cost/target attacked
- Cost/Red personnel casualty

* This procedure was used to average out small fluctuations and peculiarities associated with the simulation process.

- Cost/Red ton materiel casualty
- Blue loss in dollars/Red target attacked
- Targets attacked/fire support utilization hour
- Tons expended/target attacked
- Tons expended/weapons attacked
- Tons expended/Red personnel casualty.

3. Lockheed/USMC

Because this study addressed actual weapon systems to recommend design characteristics for land-based SSM systems and to note trends in the favorable mix compositions, it did have a mix selection process. The study commented on the difficulties entailed in the selection of an optimum: "Since it was felt that no single measure accounted for all the desirable and undesirable characteristics [of a weapon system/mix], the results were organized to show trends."⁴

Weapon systems/mixes went through the following three stages of tests or comparisons:

- (1) MOE comparisons--The measures of effects and efforts were combined into three ratios:
 - Weight over the beach required per target killed
 - Total cost per target killed
 - Required personnel casualties per cost \times weight over the beach.

These ratios were used only to make gross eliminations of clearly noncompetitive mixes.

- (2) Single system operation capabilities and requirements within the mix--Additional quantitative factors were considered in this stage, such as,
 - Excess personnel casualties (over the minimum required)
 - Aircraft sortie requirements

- Land SSM requirements
 - Targets successfully attacked by Land/Navy SSMs.
- (3) Qualitative judgments--This final stage entailed a qualitative analysis of the following weapon/mix characteristics:
- Weapon vulnerability
 - Mobility
 - Complexity
 - Ability to attack a variety of target types
 - Relative importance of the distribution of strike requirements among all weapons in the mix.

4. Naval Weapons Laboratory, Dahlgren, Study

NWL performed the only formal cost/effectiveness analysis that resulted in the selection of an optimum mix. The mathematical techniques of nonlinear regression and nonlinear programming were used to perform a fixed effectiveness, minimum cost analysis in a part of the methodology called the "Mix Preference Program." A description of the major elements of the Mix Preference Program follows.

a. Nonlinear Regression

The effectiveness data used (i.e., the MOEs listed in Table 22) are obtained from the simulation model of fire support. The results of the simulation of 128 "leading candidate mixes" are analyzed through nonlinear regression methods to generate effectiveness curves, one curve for each measure of effectiveness. These curves allow for the interpolation of effectiveness for mixes that were not among the 128 simulated mixes.

A simple linear function and a simple exponential function yielded the best fit to the simulation results. Thus, for example, a

linear regression curve relating one measure of effectiveness to the various weapon systems under study would take the following form:

$$\text{MOE} = A + \sum_{i=1}^{16} P_i X_i$$

where the X_i 's represent the quantities of the 16 different weapon systems being considered and the A and P_i 's represent the computed regression coefficients.

A curve is computed for each measure of effectiveness and each situation* with the 16 basic weapon systems as independent variables, resulting in 28 possible curves (7 MOEs \times 4 situations).

b. Nonlinear Programming

Using the cost curves computed in the cost analysis models and the curves of effectiveness computed through the nonlinear regression analysis, nonlinear programming methods can be used to determine a mix that minimizes cost while satisfying certain minimum performance levels for the MOEs and satisfying certain combinatorial constraints pertaining to mix composition.

Using those effectiveness curves that yielded statistically significant relationships (this occurred on 16 out of the 28 curves), a minimum required performance level was selected for each MOE to be the median performance of the 128 mixes.[†] These became constraints for the

* There are four situations as determined by four war games.

[†] The 128 mixes were selected in the mix generation process on the basis of being able to meet fire support requirements. Thus, the median is a median performance among effective mixes (see Appendix C).

mixes,* along with combinatorial constraints pertaining to mix composition such as:

- Constraints that limit the mix selection to the region where the effectiveness data are valid.
- Other constraints pertaining to specific assumptions, e.g., certain weapons cannot simultaneously be in the mix.

Even if the linear regression equations are used, the problem is still nonlinear because of the discontinuities associated with the cost curves and certain of the combinatorial constraints. The solution is further complicated by the desirability of integer solutions.

The technique of "branch and bound" was employed to facilitate integer solutions and to reduce the overall problem to a series of problems suitable for solution using a nonlinear programming technique, the Sequential Unconstrained Minimization Technique (SUMT). NWL gives the procedures in Refs. 28 and 29 as the source of their approach.

5. U.S. Army Combat Developments Command/Legal Mix IV

Although not a mix study in terms of the three supporting arms, the Legal Mix study was conducted to determine an "optimum mix" of field artillery systems.

The preferred mix was based on a series of analyses, some subjective and some quantitative. These analyses are summarized in the Legal Mix IV write-up in Appendix C and include: survivability, mobility, performance against a nonnuclear threat, performance against a nuclear threat, cost, and subjective considerations not adequately addressed in

* e.g.,
$$A + \sum_{i=1}^{16} P_i X_i \geq \text{MOE}_j \text{ (median)}.$$

one of the previous analyses. The final selection of a preferred mix was based on a subjective consideration of all the analyses that had been conducted.

The survivability and mobility analyses were entirely subjective. The optimum nonnuclear mix was chosen as a result of a series of analyses: the Trial Mix Analysis, the Leading Mix Analysis, and the Mix Level Analysis. These are described in Appendix C. Leading mixes were selected using the measures of effectiveness and efforts in Table 22 in both constant effectiveness and constant efforts simulations. When comparisons were not clear, subjective factors like reliability and traverse capability were considered. Finally, the optimum nonnuclear mix was chosen in the Mix Level Analysis by considering graphs of MOEs versus cost, MOEs versus the number of battalions, and ratios of effects achieved per total cost as a function of number of battalions.

This optimum mix plus other leading mixes, is simulated in a nuclear situation to determine nuclear capability.

B. Evaluations of Strengths and Weaknesses

The mix selection techniques used in current studies present several problems to the analyst. They are not problems unique to fire support analysis but are commonly encountered in all forms of system analysis. A brief discussion of these problem areas, or weaknesses, follows. There is also an evaluation of the NWL approach. It is singled out for specific comment because of its uniqueness and completeness and because the NWL study is the only one with the primary objective of selecting an optimum mix of all three supporting arms.

1. General Weaknesses

The following problem areas pervade the mix selection procedures:

- Inconsistency in the definition of MOEs
- A paucity of methods for combining MOEs
- Difficulty in carrying out sensitivity analyses
- Inability to perform risk analyses
- The improper use of cost/effectiveness ratios.

Inconsistency in the definition of MOEs and a paucity of methods for combining MOEs result from the same basic problem: subjective judgments play a major role in both. There are many MOEs for fire support analysis because many people are involved in such analyses. The relative importance of MOEs and of measures of efforts will vary depending on the personal convictions of the analyst or decision-maker involved. The most immediate result of this is a proliferation of MOEs that makes using the results from different studies very difficult.

Studies employing fixed effectiveness avoid some of the problem of combining MOEs. NWL does this, for example, by fixing all MOEs at a specified level and computing mix costs. CNA does the reverse, fixing cost and then computing effectiveness. Obviously these procedures involve subjective judgment as well, but they do not require devising ways of making quantitative estimates of the relative importance of the MOEs.

The difficulties associated with performing sensitivity analyses result from the cumbersome methodologies many studies use. It is generally too time consuming and too costly to conduct such analyses. NWL efficiently performed sensitivity analyses on particular issues at the mix preference level. However, analysis of fire support in a different environment entailed the considerable effort of another war game.

Risk analysis is a form of sensitivity analysis. In fact, risk assessment is usually the reason for doing sensitivity studies. However, the probabilistic nature of risk is not reflected in the way sensitivity analyses are ordinarily performed. The risks associated with making a

decision should be measured in terms of the likelihood of the possible consequences and costs that can result from that decision. Putting this in terms of the mix selection problem, the knowledge of the risks associated with selecting a specific fire support weapons mix is invaluable to a decision-maker. He may make an entirely different decision when he is familiar with the risks than he would when presented with point estimates of performance and costs. A classic example is the choice of a uniformly less effective system over a more effective one that is generally expected to have a lower cost but runs some risk of a large cost overrun. This is typical of the choice that must be made between existing systems and systems requiring significant R&D investments.

None of the mix studies reviewed include probabilistic risk analysis because none of them associated probabilities with MOEs or costs. This represents a weakness that should be corrected if results are to be most useful to those selecting mixes.

The improper use of cost/effectiveness measures often results from the manner in which cost and effectiveness information is combined. Measures such as cost per kill and kills per weight over the beach can be misleading if not properly used. Such measures are good generally only when there is a linear relationship between effectiveness and cost. If there is no linear relationship, then such ratios must be defined separately for each of the regions in which they are used. For example, quoting a measure such as \$1,000 per kill leads one to expect that \$10,000 will yield 10 kills, and \$ 1 million will yield 1000 kills, and so on. In reality, such a linear relationship seldom exists over a sizeable region. Thus, to quote such numbers without specifying the regions over which they apply is generally incorrect. The Lockheed/USMC study recognizes this restriction and is careful to point out that its cost-effectiveness measures only apply to specific regions of performance and costs.

The Lockheed/USMC study is the only study other than the NWL Study that develops a formal structure for selecting a mix based on cost/effectiveness considerations. Lockheed develops a step-by step procedure and a hierarchy of MOEs that provide a logical selection process. This is a viable approach that can be used when a more quantitative approach like NWL's is deemed inappropriate, as it should be when adequate data are not available. The Lockheed approach automatically includes certain aspects like mobility and complexity that are difficult, if not impossible, to handle quantitatively. It is possible that such qualitative aspects of the problem can be overriding, in which case the Lockheed approach is particularly appropriate and more quantitative methods are inappropriate.

2. The Naval Weapons Laboratory Approach

The NWL approach to mix selection is unique. It offers a mathematical method of combining diverse MOEs, measures of effort, and costs to yield estimates of an optimum mix of artillery, naval gun, and air systems. It uses a technique that facilitates sensitivity analyses more than other fire support studies of comparable magnitude. Although time consuming, the nonlinear regression techniques, in combination with the nonlinear programming model, provide a flexible vehicle for sensitivity analyses that is not found in the other studies.

The NWL approach has some weaknesses, too. From the point of view of someone trying to use the NWL methods, the major weakness is the dearth of documentation for the mathematical models. It is impossible to reconstruct from available documentation how they performed some of the calculations. A particular problem that is not adequately addressed in the NWL reports is how the integer nature of squadrons, batteries, and ships is handled by the continuous nonlinear programming model, SUMT. Rounding off for such units can create many problems. References 30 and 31 state that branch-and-bound techniques were used to force integer

solutions, but this is not exactly the case. Additional constraints were put on the mix to force integer solutions* for some of the variables--but not for all. This approach does not mathematically guarantee an optimum solution. However, NWL personnel have stated to the authors that their intimacy with the problem and the sensitivity analyses they performed made them certain they had found the optimum. This means that the use of the NWL approach entails considered analyst interaction in the search for an optimum--not an unusual situation.

In setting up the fixed effectiveness analysis, NWL selected the median values of the MOEs from the distribution of all candidate mixes as the fixed level of effectiveness. The assumption implicit in doing this is that the importance attached to the MOEs attaining at least their median value is the same for all MOEs. In other words, the MOEs are all equally weighted. Whether this represents a weakness depends on one's personal assessment of the MOEs relative importance.

C. Alternatives

1. General

No new alternatives for mix selection are presented here. The NWL and Lockheed/USMC techniques provide two approaches that can be used in a broad spectrum of mix studies. If the availability of data warrants it, the NWL approach is superior, but the frequent lack of data in vital areas will often dictate the more subjective Lockheed/USMC approach. There are some techniques lying between NWL's and Lockheed's, such as the RAC linear programming approach.³² However, they constitute dilutions of the comprehensive approaches of these two studies.

* For example, $\sin(\pi x) = 0$ forces x to be an integer and is acceptable by SUMT.

The NWL and Lockheed methodologies do have weaknesses, as described previously. Because the major weakness in the NWL approach appears to be its modicum of documentation, familiarization with the details of the approach would be difficult. However, it can be done, particularly since it is not the techniques that are new but the way NWL uses them. The assumptions about integer solutions, as described in the previous subsection, must be recognized when the NWL approach is used. Their importance will vary, depending on the exact nature of the problem under study. The evaluation of their impact should be an integral part of the methodology in future studies.

There is an obvious alternative to the deterministic nature of the NWL and Lockheed mix selection procedures and that is to model the uncertainty. However, this is not a solution that can be confined to the Mix Selection Key Element only. It has to be included in the other key elements too, if the right kind of data are to be available for mix selection. Methods for including uncertainty have been discussed previously and they apply to mix selection as well. An indication of the type of study results that the inclusion of uncertainty in the entire methodology can lead to is given below in a brief discussion of the elements of a cost/effectiveness analysis.

2. Cost/Effectiveness Analyses

Although no presentation of alternatives is deemed necessary for the mix selection element, certain guidelines are worth noting as applicable to any cost/effectiveness analysis, such as the mix selection problem. They are to:

- Select succinct yet useful MOEs.
- Do an initial screening of alternatives to make obvious eliminations.

- Use fixed cost or fixed effectiveness analysis, if possible.
- Include risk, if possible.

The motivation for most of these guidelines is included above in the discussion of weaknesses. The possible method of implementation is discussed in some detail below.

A large number of MOEs inhibit mix selection. To be useful, the set of MOEs should comprise a small number of succinct yet tractable measures; care must also be taken to avoid too aggregated a set of MOEs for that can be impractical as well. For instance, for the sake of presenting study results concisely, often only one or two aggregated MOEs are chosen. They may conveniently display differences among mixes, but they also can be unsatisfactory because, although they may be analytically appealing, they cannot be interpreted in terms of real-world combat situations. Thus, the analyst must seek MOEs that are few in number and yet rich in tactical meaning. A part of this process is to identify relationships among MOEs so that, by establishing the value of one, the values of others are determined. Also, the possibility of combining measures should be pursued. Most of all, the tactical significance of the candidate measures should be assessed and the opinions of those who must select mixes should be sought before the set of MOE is defined.

The second guideline above calls for the elimination of mixes that are either infeasible or "dominated." Infeasible mixes are those that either cost more than budgeted for or fail to meet minimum effectiveness requirements; dominated mixes are mixes that yield less effectiveness than lower cost mixes. Direct comparison of the MOEs and the costs of alternative mixes will generally lead to eliminations of this type.

The use of fixed cost or fixed effectiveness analysis, the third guideline, alleviates the difficulties of combining cost and effectiveness in an acceptable way. These difficulties were discussed in the

previous subsection. NWL's fixed effectiveness analysis is an especially good example of this approach, partly because it demonstrates the difficulties of fixed effectiveness analyses. The NWL approach relies on the use of a fairly complicated nonlinear regression technique to provide fixed levels of effectiveness as the mix composition varies. Fixed cost analysis can be equally as difficult to implement. However, in the absence of fixed cost and fixed effectiveness, the cost/effectiveness procedures generally reduce to simply producing plots or tables of effectiveness versus costs. The selection among mixes then involves judgments as to how much should be spent for incremental increases in effectiveness. This, in effect, is the Lockheed/USMC approach.

Finally, risk analysis should be included if possible. The uncertainty inherent in both the cost and effectiveness data is a complicating factor for the cost/effectiveness analysis, but its importance cannot be overrated. To make consistent and effective decisions, the process of ranking mixes should include the statistical variability inherent in the measures on which the ranking rests. In other words, decision-makers should be given an estimate of the risks entailed in choosing each mix. One approach to combining cost and effectiveness is to consider the risk that the decision is the wrong one and to select the alternative that minimizes that risk. Although it is not easy to define what constitutes a wrong decision, it can be done. Selection of a mix that turns out to be incapable of meeting minimum effectiveness requirements or that costs too much could be the definition of a wrong decision, for example.

An example of what can happen when cost and effectiveness uncertainties are not included in the analysis is shown in Figure 7, where the cumulative probability distribution function of an MOE is plotted versus the MOE. (Similar curves could be drawn for cost distribution functions.) In a fixed cost analysis, if only a point estimate of the

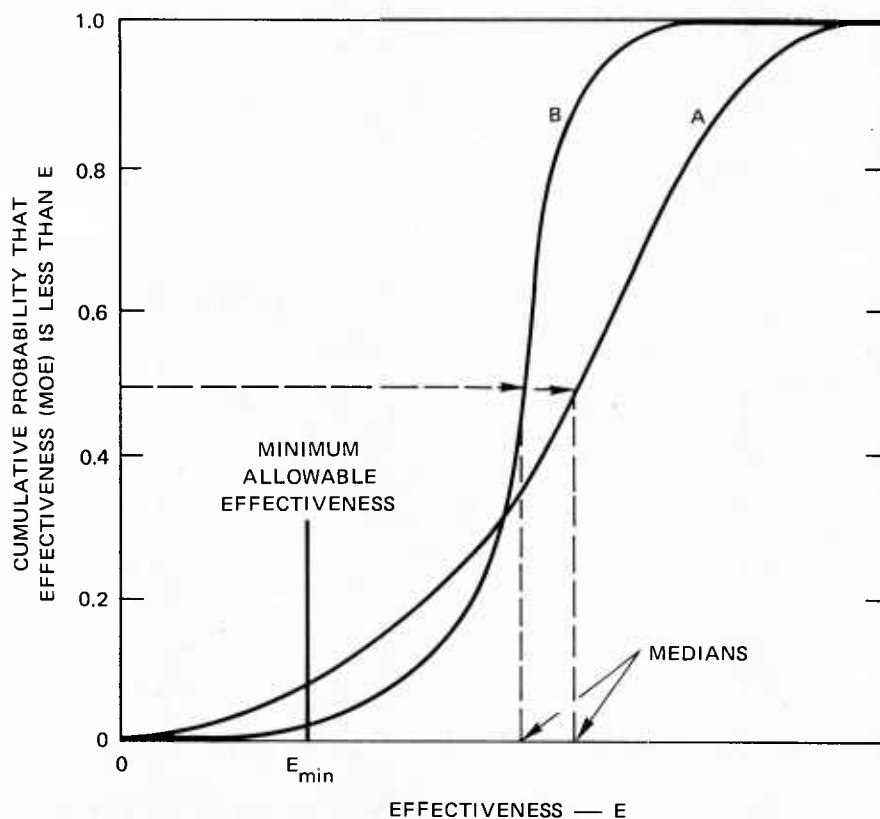


FIGURE 7 EXAMPLE OF THE ROLE OF UNCERTAINTY IN MIX SELECTION

MOE like the median indicated by the dashed line in the figure is available, Mix A would be selected because its median MOE is larger than Mix B's. However, in view of the additional data in the figure, there may be sufficient justification for choosing Mix B. The true effectiveness of Mix B can be estimated with greater confidence, and in addition it shows less risk of not meeting minimum requirements. On the other hand, Mix A offers considerable potential for exceeding the performance of Mix B. All these factors should be weighed in the selection process. The point is that existing fire support methodologies do not include uncertainties so that such information is not available to play a part in the decision-making process.

The actual procedures for including uncertainties are straightforward and have been described previously. Gathering the requisite input data may cause problems, but no more so than it ordinarily does when only point estimates rather than distributions are sought. In fact, data in the form of distributions are generally more valid and easier to obtain, if they are correctly pursued, than are point estimates. This is true because, when the value of a parameter is uncertain, the analyst should logically be more willing and able to define a region within which the true value of the parameter lies than he is to make a point estimate. As an example, the size of the anticipated threat is usually a random variable, for which the threat forecasting expert can make estimates such as: "The chance of there being more than 50 tanks is 30 percent" or "The chance that the number of tanks is between 30 and 70 is 90 percent." He would feel more confident making estimates like these than he is making such point estimates as "The mean number of tanks is 40." The same comments are true of the cost data-gathering procedures.

Including uncertainty provides more realism because the real world is uncertain; including uncertainty provides a better picture for the decision-maker because it estimates risks associated with decisions. For these reasons the inclusion of uncertainties should receive careful consideration when the fire support mix evaluation methodology is formulated.

VI COST ANALYSIS

Cost analysis is a subject unto itself and is worthy of detailed study. Within this research effort, however, greater emphasis has been placed on the operational effectiveness of mixes than on their costs. The importance of costs to any mix preference selection is recognized to be equal to effectiveness but, methodologically speaking, costing is at a greater state of development.

In this section the costing techniques used in the researched fire support studies are identified, the various cost factors enumerated in Appendix C are described and discussed, the strengths and weaknesses of the different costing techniques are assessed, and some thoughts on alternatives are presented.

A. Techniques in Use

Using the available analytical costing techniques as a structural base, the extent to which these available techniques have been used in the reviewed studies is identified in Table 23. Each of the various techniques is now described.

1. Type of Costs

Life-cycle costs refer to the total costs generated by a system from the time it is conceived until it is retired from service. Costs are estimated on this basis whenever, as is usually the case, the downstream operations and maintenance costs of a system are significant compared with the initial cost of R&D and of investment required initially to field the system. Life-cycle costs are applicable normally

Table 23

COSTING TECHNIQUES* USED IN PAST STUDIES

Technique	Agency/Study						
	NWL	RAC	SRI/ MAFAR	WSEG	CNA	Legal Mix	Lockheed/ USMC
Type cost							
Life cycle							
Program	X	X	X	X	X	X	
Cost coverage							
Direct mission				X			
Direct mission plus support	X		X		X	X	X
Cost sources							
RDT&E	X	X	X	X		X	
Investment	X	X	X	X	X	X	X
O&M	X	X	X	X	X	X	X
Cost phasing							
Time phased	X						
Static		X	X	X	X	X	
Time period (years)	10	10	7 [†]		5-20	10	1
Terminal/residual value	X						
Discounting	X						
Inflation	X						
Cost structure							
Zero based	X [‡]		X		X	X	
Incremental							
Multiple use cost allocation	X						
Uncertainty							
Sensitivity analysis	X		X			X	
Cost assumption							
Peacetime	X	X	X	X	X	X	X
Wartime		X	X				

*Based on definitions of techniques as contained in this section, which may differ from those used in a researched study.

[†]Includes 7 years of peacetime and 90 days of combat operations.

[‡]Incremental cost used for multimission systems.

where the system under consideration has a definable service life at the end of which it is expected to be retired in favor of technologically superior successor systems.

Program costs, on the other hand, are typically calculated when the "system" under consideration is actually a combination or mix of many systems, each of which typically exhibits a life cycle, whereas the multisystem combination, or "program," does not. Because each component system has different initial operational capability dates and is replaced by successor systems at different downstream dates, the program has a virtually indefinite service life and does not exhibit a single retirement date that might be considered the end of its "life cycle." When program costs are the appropriate costing convention, it is customary to choose a certain arbitrary period of time over which the program costs will be calculated for each alternative. Normally, this would be at least ten years to permit the recurring operations and maintenance costs to exert their full and proper influence on the total cost estimate.

Opportunity costs, a third type of cost, represent the potential benefits associated with rejected alternatives. This concept is often used in commercial transaction evaluations, but only rarely in military systems studies. None of the studies evaluated herein addressed this type of cost. It is typically not used in military studies because the opportunity costs of interest are actually represented by the potential benefits of the rejected alternatives, which are almost always taken into account.

2. Cost Coverage

Direct mission costing would cover only those operational elements engaged on the battlefield and would ignore the costs of supporting elements. This approach is permissible only if the supporting

elements are the same for each competing alternative, in which case they can properly be neglected if the purpose of the study is merely to select among the several competing alternatives. If, on the other hand, the purpose of the study is also to forecast the budgetary implications of the decision, then the supporting elements must be included as a nonnegligible fiscal reality.

3. Cost Sources

The traditional sources of cost are the nonrecurring RDT&E and initial investment costs, as well as the recurring operations and maintenance (O&M) costs. A thorough cost analysis will necessarily include all three sources if there is significant cost generated by each. For decision-making studies only future costs are of interest since any decision to be made as a result of the study cannot influence costs already accrued, or "sunk," prior to the decision.

4. Cost Phasing

Time-phased cost estimates (which show future costs in fiscal year increments) are usually preferable to static costs (which lump all future costs into a single sum) whenever the cash flow requirements of competing alternatives differ or when it is desired to access the year-by-year budgetary impact of the alternatives. Time phasing is essential if the discounting technique is to be used as discussed below.

5. Time Period

As mentioned earlier, the time period covered by the cost analysis must be of long enough duration to permit the full impact of recurring operations and maintenance costs to be felt in the analysis. Ten years is often chosen arbitrarily; other time periods may be more appropriate depending on the particular circumstances.

6. Terminal/Residual Value

The terminal or residual value of a system at the end of its effective life cycle should be taken into account as a negative cost in the cost analysis if this value is expected to exceed significantly the necessary costs of dismantling and disposal.

7. Discounting

Discounting to "present value" the future costs of a system is a technique for recognizing the time value of money, i.e., that a dollar today is worth more than a dollar tomorrow by the amount of interest that it might earn in the private sector during the interim. Discounting is applicable whenever competing alternatives exhibit different cash flow patterns over time. For example, a system whose costs are high initially and low later on will be at a disadvantage under discounting compared with a system whose costs are low initially and high later on, although the total costs of the the two systems are the same. The choice of a discount rate can also be important in the results; usually 10 percent is used unless special circumstances warrant otherwise.

8. Inflation

Inflation effects are of interest whenever future annual budget levels are critical in evaluating system alternatives. The choice of an inflation rate for future projections is, of course, highly uncertain; one benchmark is the estimated average 5-percent rate at which prices paid by the federal government for goods and services rose during 1965 to 1970.

9. Cost Structure

Zero-based costs refer to the total cost of a system, including all its parts whether or not they are all changed by a proposed alternative under consideration. This type of costing is applicable where the unchanged portions of the competing alternatives are not considered to be of equal cost and therefore must be included in any comparison of the alternatives. Incremental or marginal costing, on the other hand, wherein only the costs of the changed portions would be considered, is applicable in the opposite case.

10. Multiple Use Cost Allocation

Allocation of costs to multiple uses may be desirable for analyzing a system whose normal operational capabilities include other capabilities than the particular ones under primary consideration in the analysis. For example, if an aircraft is assigned to fire support missions and unrelated cargo transportation missions, then an analysis of the costs of this aircraft in a fire support study should, if practicable, assign to the fire support mission only a portion of the aircraft costs, not all of them. There are several techniques for performing this allocation, including the percentage method^{*} and the two-system method.[†]

^{*}The percentage method applies to systems assumed to be divisible into subsystems, each of which can be classified as being related to a particular mission or on a joint subsystem. The total cost of the joint subsystem is allocated to the mission in direct proportion to appropriate characteristics of the mission subsystem.

[†]The two-system method applies to a technique in which two systems are designed and costed. The first system is designed as it is expected to be built. The second system is designed, omitting the mission subsystem for which the incremental cost is wanted. The incremental cost is then defined as the difference between the costs of these two systems.

Such allocations tend, however, to become artificial and to lose credibility so that they must be used with the utmost discretion and only under appropriate circumstances.

11. Cost Uncertainty

Uncertainty in a given system cost estimate is important whenever the range of uncertainty is so large that it may overshadow the calculated differences in costs between competing system alternatives. In such a case it is misleading to submit a single-valued cost estimate for each alternative to the decision-maker. Instead, high, expected, and low cost values might be submitted to show the possible range of estimated costs; or the estimates can be presented in terms of the estimated probability that the true costs of the system will lie between two given values.

12. Sensitivity Analysis

When the uncertainties involved in the cost analysis are substantial it is also generally desirable to perform a cost sensitivity analysis wherein the uncertain cost-governing elements of the cost model are varied over a likely range of values, and the impact of this variation on cost model output is noted. Such an analysis will very often show that a variation in the values of the uncertain cost elements has little effect on the cost estimate and that this type of uncertainty is therefore not a critical issue.

13. Cost Assumption

Lastly, an assumption must be made by the analyst about whether the system under study is to be costed as though it were in a peacetime or in a wartime environment. Usually, in wartime battle conditions a

system will experience greater usage, attrition, expenditure of expendables, and so on than in peacetime, and the costs would be measurably greater. However, if the system under consideration is not much affected by battlefield conditions or if the applicable wartime usage and attrition factors are not available for the analysis, peacetime conditions are often assumed.

B. Evaluation of Strengths and Weaknesses

In undertaking a cost analysis of alternative mixes of fire support systems, the analyst encounters some peculiarities that can substantially influence his choice of analytical techniques.

The aircraft and ships that take part in the fire support mission are typically multimission systems, and a high quality cost analysis should at least address the problem of allocating such a vehicle's costs to its several missions, perhaps using one of the allocation techniques described above.

A fire support mix is usually a combination of many systems having very different life cycles. The mix as a whole can therefore be thought of as a program rather than a system, and "program" costing would probably be more applicable than "life cycle" costing for fire support study.

Fire support systems appear to exhibit another unusual feature that is important to the cost analyst: the systems, in a typical operational environment, will probably expend a large quantity of expendable ordnance items, accruing recurring costs that will certainly be very substantial in relation to the initial nonrecurring costs of R&D and investment. For this reason, inclusion of O&M costs in the fire support cost model and extending the time period coverage of the analysis to a substantial period would appear strongly advisable. In this way an accurate assessment of the relative costs of alternative mixes can be better assured.

In Table 23 it can be seen that some uniformity exists in the application of costing techniques. A high proportion of the studies have considered: program costing rather than life-cycling costing; support costs in addition to direct mission costs; RDT&E, investment, and O&M costs; static rather than time-phased costs; substantial system-in-service time periods; zero-based rather than incremental costs; and peacetime conditions.

The techniques employed are generally advantageous in that they indicate that cost analysts are applying the various costing techniques judiciously. However, more consideration should be given to wartime conditions, time-phased costs, terminal/residual value, discounting, inflation, mission allocation, uncertainty indications, and sensitivity analyses. Few of the studies, in fact, considered the effects of inflation or the extent of analytical uncertainty in the costs presented.

The more recent studies seem more sensitive to the importance of costs in the cost/effectiveness assessment than do the earlier studies. This is probably attributable to the growing emphasis being placed on costs by decision-makers. The NWL, MAFAR, and Legal Mix studies, for example, are relatively recent and appear to be the most complete and best documented of those analyzed. The lack of adequate documentation, i.e., detailed explanation of method and complete citation of data sources, is a primary weakness observed in these studies.

C. Alternatives

As the interest of decision-makers in costs seems to be continuing, it is anticipated that substantial improvements in the selective application of advanced costing techniques to future fire support studies will be made.

Good decisions depend on accurate, real-world analysis of the costs of alternative systems. If the alternatives exhibit substantially different downstream cash flows (as they often do), they cannot be reliably compared unless discounting is used; if there is serious disagreement on the applicability of a specific discount rate, a simple analysis of the sensitivity of costs to discount rate should be prepared and included in the report. Inflation rates can be similarly handled. But the mere presence of uncertainty about rate should never be used as the excuse for ignoring the impact of these two important environmental factors on systems costs and system budgets. Finally, discounting can generally only be undertaken if costs are calculated on a time-phased rather than a static basis.

Costing will always include uncertainties, particularly for future systems. The feasibility of including decision theory and risk analysis in costing techniques is clear. More prevalent use of such techniques can do much to strengthen the usefulness of fire support studies.

Lastly, adequate documentation must be provided explaining in detail the methodology and data sources used by the cost analyst to improve the state of the art of weapon system cost analysis.

REFERENCES

1. "MAF Fire Support Study Final Report, (U)," Vols. 1-11, U.S. Naval Weapons Laboratory, Dahlgren, Virginia (31 July 1972), SECRET.
2. "Naval Gunfire Support (U)," Vols. I-IV, Center for Naval Analyses, Naval Warfare Analysis Group (25 February 1965), Vols. I-III SECRET and Vol. IV UNCLASSIFIED.
3. "Dynamic Effectiveness Model Study (DEMS) (U)," Lockheed Missiles & Space Company, Sunnyvale, California
Vol. 1, "Summary (U)," (1 Nov. 1965), SECRET/NOFORN.
Vol. 2, "Fire Support Evaluation Model Development and Checkout (U)," (1 Nov. 1965), SECRET-RD.
Vol. 3, "Computer Program Handbook," (1 Nov. 1965) UNCLASSIFIED.
Vol. 4, "Model Modifications and Evaluation (U)," (1 March 1967) SECRET.
Vol. 5, "SEASian Non-Nuclear Environment (U)," (1 March 1967) SECRET.
Vol. 6, "Korean Environment--(DEMS III) and Program Modifications (U)," (1 December 1967) SECRET.
Vol. 7, "European Environment (DEMS IV) (U)," (31 August 1969) SECRET.
Vol. 8, "MRL Evaluation Phase Report (U)," (12 February 1970) CONFIDENTIAL.
4. "U.S. Marine Corps Fire Support Weapon Systems Study (U)," Lockheed Missile & Space Company, Sunnyvale, California (1 July 1961).
Vol. 1, "Study Summary--Mix Evaluation (U)," CONFIDENTIAL.
Vol. 3, "Environmental Supporting Study (U)," CONFIDENTIAL.
5. "Requirements Study on Fire Support Systems (CMC Project No. - Unnumbered)," Marine Corps Landing Force Development Center, Marine Corps Schools, Quantico, Virginia (29 April 1963) SECRET-RD/NOFORN.
6. "The Tank Weapon System," Systems Research Department, Department of Industrial Engineering, Ohio State University, Columbus, Ohio.
A. B. Bishop and S. Stollmack (eds.), Final Report RF-573, AR 68-1 (September 1968).
A. B. Bishop and G. M. Clark (eds.), Final Report AR 69-2A (October 1969).

- _____, Final Report AR 69-2B (September 1969).
G. M. Clark and L. C. Moss (eds.), Final Report AR 69-3A (June 1969).
_____, Final Report AR 69-3B (June 1969).
A. B. Bishop and G. M. Clark, Final Report AR 69-4 (June 1969).
7. Seth Bonder et al., "Development of Analytic Models for Defense Planning," Systems Research Laboratory, University of Michigan, Ann Arbor, Michigan (September 1970).
 8. "Analysis of Fire Support and Fire Support Systems in Ground Combat (U)," Research Analysis Corporation, McLean, Virginia (May 1971), SECRET.
 - N. E. Mitchell et al., Vol I, "Value of the Fire Support and Fire Support Systems (U)."
 - W. W. Edwards et al., Vol. II, "Examination of Some Fire Support Issues (U)."
 - W. H. Jackson et al., Vol. III, "Descriptions of Some Fire Support Systems (U)."
 9. "Force Requirements Analysis Model Documentation for Commanders, Operators, and Programmers," Research Report, Naval Warfare Research Center, Stanford Research Institute, Menlo Park, California (May 1970).
 10. H. B. Wilder, Jr., et al., "Marine Corps Attack and Fighter Requirements (MAFAR) (U)," Naval Warfare Research Center, Stanford Research Institute, Menlo Park, California (July 1968).
 - Vol. I: "Main Report," SECRET.
 - Vol. II: "Appendixes," SECRET.
 11. "LEGION," Strategy and Tactics Analysis Group (STAG), Bethesda, Maryland (31 January 1968).
 - Vol I, "Players Manual with Appendices."
 - Vol. III, "LEGION Systems."
 12. J. Honig et al., "Review of Selected Army Models," Review Report, Department of the Army, Washington, D.C. (May 1971).
 13. "Optimum Mix of Artillery Units, 1975-1980 (U) (Short Title: Legal Mix IV), Final Study, U.S. Army Combat Developments Command, Field Artillery Agency, Fort Sill, Oklahoma (June 1972), SECRET-RD/NOFORN.
 - "Executive Summary."
 - Vol. I, "Summary, Main Report and Methodology, Appendix A-I."
 - Vol. II, Appendix J: "Discussion/Analysis, Europe."
 - Vol. III, Appendix K-L, "Cost/Effectiveness Data for the Candidate Mixes and Threat."

- Vol. IV, Appendix M, "Cost Model."
- Vol. V, Appendix N, "Effectiveness Model."
- Vol. VI, Appendix O-P, "Basic Data and Cost Data."
14. "Evaluations of Tactical Weapon Systems for Fire Support of Land and Amphibious Forces in the Period 1968-1975 (U)," Part II: "Limited War," Vols. I, II, and III, WSEG Report 112, Weapons Systems Evaluation Group, Arlington, Virginia (June 1967), SECRET/NOFORN.
 15. WSEG Study, Vols. I and II.
 16. "The Tank Weapon System," AR-69-2A.
 17. "Combined Reconnaissance, Surveillance, and SIGINT Model (CRESS)," Final Report, Stanford Research Institute, Menlo Park, California (November 1968).
 - Vol. I: "Summary Description," UNCLASSIFIED.
 - Vol. II: "User's Handbook," UNCLASSIFIED.
 - Vol. III: "Computer Programs," UNCLASSIFIED.
 - Vol. IV: "Sensor Characteristics and Combined Usage of Sensors," SECRET.
 18. DEMS, Vol. 6.
 19. R. Snow and M. Ryan, "A Simplified Weapons Evaluation Model," RM-5677-1PR, The Rand Corporation, Santa Monica, California (May 1970).
 20. "Naval Gunfire Support (U)," Vol. II of CNA Study, Appendix C.
 21. MAFAR, Vol. 2.
 22. "Ammunition and Fuel Distribution Systems for Marine Corps Combat Operations (U)," Final Report, Naval Warfare Research Center, Stanford Research Institute, Menlo Park, California (July 1967), SECRET.
 23. "Systems Analysis of Seaborne Mobile Logistics System Concept (1975-1985)," Naval Warfare Research Center, Stanford Research Institute, Menlo Park, California (May 1969).
 24. "Logistics Support Ashore for Sustained Operations (1980-90) (U)," Final Report, Naval Warfare Research Center, Stanford Research Institute, Menlo Park, California (August 1970) CONFIDENTIAL.

25. "Support Requirements for a Composite Marine Aircraft Group (U)," Final Report, Naval Warfare Research Center, Stanford Research Institute, Menlo Park, California (January 1967) SECRET.
26. "Pre-D-Day Fleet Marine Force Materiel Requirements and Distribution System (1975-80) (U)," Final Report, October 1971, Naval Warfare Research Center, Stanford Research Institute, Menlo Park, California.
Volume I: "Analyses and Findings (U)," SECRET.
Volume II: "Algorithms for the Construction of a Table of Supply Under Size Constraints and for the Simulation of Item Processing at a Marine Corps Supply Center."
27. "Naval Gunfire Support (U)," Vol. I of CNA study.
28. A. P. Jones et al., "A Branch-and-Bound Algorithm for Multilevel Fixed-Cost Problems," Research Analysis Corporation, McLean, Virginia (October 1967).
29. D. Gross et al., "A Branch-and-Bound Algorithm for Allocation Problems in Which Constraint Coefficients Depend on Decision Variables," Research Analysis Corporation, McLean, Virginia (August 1968).
30. H. W. Loomis, "The Mix Preference Program (Fire Support Study Working Paper Number 3)," Technical Note TN-K/8-70, U.S. Naval Weapons Laboratory, Dahlgren, Virginia (February 1970).
31. MAF Fire Support Study, Vol. 2.
32. W. W. Edwards et al., "A Methodology for Determining Support Weapon System Mixes," Volume I: "Main Report," Research Analysis Corporation, McLean, Virginia (March 1972).

Part III

SYNTHESIS OF METHODOLOGICAL ISSUES

I INTRODUCTION

This Part provides a summary of the salient methodological issues raised in previous sections of the report. Most of these issues are discussed in Part II in methodology assessment; others originate directly from the nature of the fire support system and therefore relate more to the discussions in Part I. As would be expected, many of the issues identified are not unique to fire support studies, and thus the comments that follow have broader implications than just those associated with fire support.

Because of the importance of the problems caused by deficiencies in study input and because deficiencies occur so frequently, input data are treated below in Section II as a separate subject. Other methodological issues are addressed in Section III, where they are presented in the same general format of Part II, that is, they are discussed as they pertain to the overall approach to and the key elements of the fire support system. Lastly, the impact on fire support methodology of the future trends and influences, as delineated in Part I, is identified.

II INPUT DEFICIENCIES

A. Availability and Credibility of Data

The complaint most consistently voiced about the results of operations and system analyses is not aimed at the techniques used but at the credibility of the input employed. Fire support mix analyses are no exception. The most elegant of fire support evaluation methodologies will not improve the acceptability of results derived from unacceptable input data. The first priority of any fire support mix study must be to address this issue and to develop good and acceptable input data. This includes specification not only of system and operator performance characteristics, but also specification of tactics, operations, and the overall scenario structure.

The analyst must keep the input availability issue in mind during the development of the study methodology. Some of the difficulties in finding the required input data stem directly from the unrealistic demands of the study methodology. The model developer is sometimes tempted to relegate to input those items that are difficult to handle as a part of the methodology, without regard to the availability of such input.

Related to this are the acceptability and credibility of available input data and tactics. It is certainly essential that the analyst believe in the data used, but it is equally essential that those who must act on the results believe in them. A close coordination between the analyst and user is mandatory in studies of the magnitude of most mix studies, particularly in the input formulation stage.

Thus, the amount of effort spent in developing input and in coordinating it with the users of the results is a fundamental factor in any fire support study.

B. Specific Deficiencies

The research reported in Part II provides insight into areas that show data gaps in particularly important input. These gaps are of interest to those concerned with fire support mix evaluation because they identify the areas where resources can be most fruitfully placed. Future studies and tests can be guided by the need to fill these gaps.

1. Scenarios

The scenario drives the entire analysis. Quantitative/qualitative changes in target/mission lists based on the scenario significantly affect the fire support system mix. Yet existing studies display a lack of consistency in the character of the scenarios they use. Not only do the target arrays differ, but the length and portion of the operation emphasized differ as well. A set of realistic scenarios designed especially for fire support studies is needed. These scenarios must encompass a spectrum of contingencies and be flexible enough to handle innovative as well as existing doctrine and tactics. The numbers and types of targets and missions derived from these scenarios must also be validated as representative of fire support requirements.

2. Aggregated Measures of Performance

Part II describes the desirability of an aggregate model of the fire support system and also points out that the major problem with such a model is its input requirements. Few techniques exist for converting detailed system characteristics into aggregated measures of performance for combat units.

3. Target Acquisition

Target acquisition is an important link in the fire support system from detection of targets to assessment of the effectiveness of the fire placed upon them. Considerable data are available on the technical characteristics of sensors, but there are important gaps in operationally oriented data. Unit-by-unit detection is important to fire support, as are operations under restricted visibility conditions, yet little data concerning acquisition exist in these areas. The realism of any assumptions made with respect to the acquisition of targets should be verified.

4. New Systems and Techniques

New systems, techniques, and tactics create a continuing demand for new study input data. This causes a special kind of input problem in that characteristics for systems of the future are often either ill defined or nonexistent. In studies of alternatives comprising both new and existing systems, the analyst must be careful not to penalize existing systems by using operational data for their characteristics and using "specs" for planned systems. Better techniques capable of quantifying the relative benefits and problems of existing and new systems are needed. These should include a consistent basis for attrition assessment and should provide for significant differences in tactical flexibility.

C. Sensitivity Analyses

Even after a thorough search for input data for a carefully developed methodology, many uncertainties in the input generally persist. These uncertainties should be quantified and the results should be presented in terms of these uncertainties. This can be done either by sensitivity analyses (i.e., repeating the analysis while varying the input) or by carrying the uncertainties through the analysis (stochastic modeling).

III OTHER METHODOLOGICAL ISSUES

A. Overall Approach

Part II begins with a discussion of the overall approach to an optimum mix study. Four fundamental issues pervade the design of the methodology. The analyst must address these issues if he is to develop a consistent and useful procedure. Suggestions on how to handle each issue are given below.

1. Model Hierarchy--Unified or Compartmentalized

The many facets of the fire support system demand a comprehensive methodology for the selection of preferred mixes. The most practical way of providing such a methodology is through a hierarchy of models, as described in Part II. The hierarchy comprises three levels of models representing three levels of detail or, conversely, three levels of aggregation. The first level is the most aggregated model and is used primarily for sensitivity analyses. The second level is a detailed model of the entire fire support system and is used for the bulk of the analysis. The third level comprises a set of supporting models that provide high resolution input to the other two levels. A surveillance model is an example of such a high resolution supporting model.

The study team must choose how to operate within this hierarchy. Because of the varying objectives of mix studies, each study will emphasize different elements of the hierarchy. However, the significance of each element must be weighed before deciding which should be included in the study and which should be ignored or handled in simple terms. Once this is done, a choice can be made between a unified or a compartmentalized

approach to the second level of the hierarchy. At this level the four key elements of the fire support system* have most often been modeled independently, i.e., in a compartmentalized fashion. This approach facilitates analysis by providing flexibility and allowing specialization. However, it usually rests on the assumption that the interactions among the elements are, at most, second order. The unified approach models the entire system in an integrated and dynamic way and in this aspect is more representative of the real world. It is, however, less flexible and more difficult to execute than the compartmentalized approach. Thus the study team must consider these trade-offs in selecting its approach--the unified, the compartmentalized, or a compromise somewhere between the two.

2. Two-Sided Versus One-Sided Models

A common weakness in existing methodologies is the use of a methodology that is one sided, in the game theoretic sense, when a two-sided approach is more appropriate. Typically, a scenario is devised, Red and Blue tactics and systems are defined, and the battle is simulated by a model. Then, to compare alternatives, Blue's systems or tactics are changed and the battle is fought again without changing the Red situation. This is not realistic and can easily lead to false conclusions. Red's tactics will certainly depend on Blue's tactics and systems. A two-sided methodology in which Red is allowed to change his tactics is often required in fire support mix studies to account for such interactions.

* The four key methodological elements of fire support viewed as a system (excluding cost analysis) are identified in Part I as: Fire Mission Generation, Fire Mission Allocation, Fire Support System Effectiveness, and Fire Support System Mix Selection.

Thus, whether the methodology should incorporate a one- or two-sided model is another issue that must be addressed by the study. Its resolution will depend on the specific objectives of the study at hand. However, it is worth noting that many existing studies have dismissed the two-sided nature of their problem without justification.

3. The Need for Sensitivity Analyses

Any fire support study will by necessity be confined to consideration of a limited number of scenarios and systems. The acceptability and significance of the study results will be enhanced if sensitivity analyses are available to answer the questions that arise about the study assumptions, i.e., the "What if" type of questions. The extent of the sensitivity analyses undertaken is an issue that should be addressed. How extensive it can be depends on the resources available and the ease of carrying it out. How extensive it should be depends on the reliability of the assumptions and input data that are the foundation of the study.

If sensitivity analysis is a factor considered during the development stage of the methodology, then it can be accomplished much more smoothly than if it is considered only after the main analysis is completed. Also, Part II suggests that an aggregated model of the fire support system will go far toward facilitating comprehensive sensitivity analyses. Such a model should be limited to modeling only those aspects of the fire support system that are deemed first order, a priori. Generally only first-order factors are of interest in a sensitivity analysis.

4. The Inclusion of Uncertainty

That many uncertainties are associated with combat is beyond question. Yet many fire support analyses are deterministic. Purely deterministic analyses provide no measure of the risks entailed in

selecting from a given set of fire support mixes, weapons, doctrines, or whatever the alternatives of the study are. Including the uncertainties associated with the input to the analyses provides the user of the output with a significantly better basis for decision-making than a purely deterministic approach.

The issue here is how extensively to incorporate uncertainty. In some studies ignoring the uncertainties may be justifiable, but if they are ignored the justification should be made clear. Inclusion of uncertainty in the methodology can take several forms. One of the simplest ways is to incorporate uncertainties as part of a sensitivity analysis. When this is done, probabilities are assigned to each set of values comprising the input for a single pass through the sensitivity analysis. Then, by combining the results of all passes, a probability distribution for the output can be developed. The more direct approach of modeling uncertainty as an integral part of the methodology is fairly common, and Monte Carlo or stochastic modeling techniques are most often used.

B. Fire Mission Generation

1. Realistic Target Arrays

Fire support target array generation procedures suffer from a lack of realism that is primarily the result of the failure to adapt Red tactics to changes in Blue, i.e., the use of "one-sided" models as described above. Part II suggests two possible remedies to this problem: a more extensive use of computer-aided war gaming and the use of two-sided computer models. Because the problem is complex, the remedies are not simple or completely defined or ranked as to their relative potential.

It is difficult to overemphasize the importance of a realistic actual target array in mix studies. Careful consideration of the appropriate generation procedures can avoid many of the criticisms of existing study results.

2. Translation of Actual Target Array to a Target/
Mission List

The target/mission list is the chronology of the disposition of Red forces as viewed by Blue fire control officers. The actual target array, on the other hand, is the true disposition of the forces. The translation procedure involves the target acquisition and C^3 functions. The issue to be faced here is how much detail is necessary when these functions are modeled. Part II suggests procedures and models that are appropriate for some studies. However, no generalizations are possible beyond noting gaps in current techniques that may require filling in future studies. In target acquisition, a prevalent gap is the inability to model detection of units (e.g., a platoon) by another unit. Most target/mission lists are static in the sense described in Part II. They are not allowed to react to the changing tactical environment that results from changes in Blue systems and tactics.

Command, control, and communications are often not handled directly in current studies. When studies do consider C^3 , the accuracy and reliability of the information passing through the C^3 system are not considered.

C. Fire Mission Allocation

In the fire mission allocation element of the fire support system (which is generally treated adequately), the major issue is what criteria should be used in the allocation process. Existing studies show a lack of consistency and realism in the allocation criteria. It is important

that the criteria used be based on operational doctrine, present or proposed, and be operationally as well as analytically appealing.

Another issue related to mission allocation is the changing nature of mission allocation. Much more automation of the allocation procedure will be found in the fire support system of the future than exists today. New mission allocation modeling techniques will be required.

D. Fire Support System Effectiveness

Part II presents results that indicate that existing studies handled the weapons effectiveness element of the fire support system well. This element is well understood, and considerable amounts of useful data are available. The issues raised are primarily those discussed above in connection with the study's overall approach. That is, such items as a dynamic model, the inclusion of uncertainty, the use of realistic models for surveillance, logistics, C^3 , and logistics are particularly important in determining weapon effectiveness.

One issue unique to the weapon effectiveness is the treatment of neutralization and/or suppression. The effects of these types of fires are not well understood and as a result are not well modeled. In fact, they mean different things in different studies. Work needs to be done to quantify the effect of these fires on the outcome of the battle and to achieve an explicit operational definition to allow better modeling.

Another area needing work is the treatment and incorporation of attrition and vulnerability within effectiveness models.

E. Fire Support System Mix Preference Selection

1. Measures of Effectiveness

The impact of the results of any fire support study will depend to a large extent on the MOEs it uses. To be useful the set of MOEs

should comprise a small number of succinct yet tractable measures. There are as many sets of MOEs as there are mix studies. A set of tactically significant and consistent MOEs and methods for combining them are needed. This set of MOEs may well take the form of a hierarchy of measures, with an overall measure for the fire support system as a whole at the highest level and lower levels that measure effectiveness in such terms as what events were accomplished (number of missions/time) and how quickly they were accomplished (completion time). Levels below this could use more concrete factors that reflect performance measures such as response time, capacity, and survivability.

Mix studies should attempt to draw on this set of MOEs according to the requirements of their particular objectives. In this way the results of various studies can be weighed, and the task of the decision-makers who must use the study results would be greatly facilitated.

2. Cost/Effectiveness Analyses

Selection among alternative mixes entails considerations of cost as well as effectiveness. If possible, these two factors should be combined in some way. There are only a few ways in which this is possible. Fixed cost and fixed effectiveness analyses are generally effectual but difficult to use techniques. Cost/effectiveness ratios are sometimes used but are appropriate only in a limited number of cases. Less quantitative mix selection procedures have also been successfully used. This type of approach, which relies heavily on subjective but expert judgment, is used in the Lockheed/USMC study. The NWL study, by contrast, uses a quantitative, fixed effectiveness analysis.

The issue relevant to analyses that relate cost to effectiveness is that there is a paucity of techniques available for performing such analyses, and those that are available are difficult to carry out and

their results are often difficult to interpret. This is evidenced by the fact that some studies avoid the problem by simply presenting the results for cost and effectiveness and make no attempt to combine them. Some manner of relating costs and effectiveness is a necessity for a cost/effectiveness analysis. This area requires considerable thought.

3. Risk

The decision to select any mix or set of mixes inherently entails risks. There are risks associated with both system effectiveness and costs, and there are risk trade-offs between new systems and existing systems. These risks are not included in the results of existing fire support mix studies. The major reason for this is the virtual lack of treatment of uncertainty in existing methodologies. It is impossible to assess the risk in fire support studies unless the uncertainties inherent in the fire support system are addressed in some way.

To make the correct choice, the decision-maker must have a measure of the risks associated with the alternative mixes. Extended use of existing risk analysis techniques and research into new ones should be an important issue in the design of future fire support studies.

F. Cost Analysis

The importance of costs to any mix preference selection is recognized as equal to that of effectiveness. Costs have been addressed to some extent in the last subsection. Part II described many of the currently available analytical costing techniques. Although the state of the art of costing is well developed, it is anticipated that substantial improvements will be made in the selective application of advanced costing techniques to fire support studies. The inclusion of risk analysis within the costing effort and the increased use of sensitivity analyses can do much to strengthen the usefulness of fire support studies.

G. Future Trends and Influences

This subsection identifies only the areas of future trends and influences that may have an impact on fire support methodology. However, it is important that the analyst review Section IV of Part I, which discusses future trends that will influence fire support in general. Although every item described in that section may not impact on methodology per se, it may well impact significantly on study scenarios, assumptions, or the credibility of input data.

1. Operational Environment

The increasing emphasis on sea basing carries with it many logistic implications that must be addressed in the weapon support system performance parameters and the system effectiveness analysis. The consideration and treatment of vulnerability of ships assume an especially critical importance under this concept.

Greater amalgamation of air and ground units means closer integration of the supporting arms and increased recognition that all the individual weapon systems form one fire support system. This amalgamation will impact on fire mission allocation techniques, possibly allowing greater efficiency in assignment of missions directly to specific fire units without regard to supporting arm.

Greatly increased amphibious objective areas with greater ship-to-shore and inland distances carry model implications in that more computer storage may be needed. Also, greater importance will have to be placed on the interactions between the fire support system and the logistic/mobility system.

The increased likelihood of conflict in urban areas connotes implications for fire mission generation techniques because of significant differences in such target parameters as type, distribution, and hardness.

2. Threat

New enemy weapon systems and an increase in the three-dimensional nature of the threat, with a concomittant increase in the rapid movement of forces, are postulated. These developments will have an effect on the desired performance characteristics of friendly weapon systems, in addition to their direct impact on the fire mission generation function.

3. Infantry Combat System/Supporting Arms Weapons

Trends and new influences in these areas are all pervasive. They affect the entire environment and substance of fire support since the reason for having a fire support system is to support the infantry in accomplishing the commander's objective. Methodologically, probably the greatest influence is in providing adequately for the three-dimensional nature of the conflict.

4. Other Combat Functional Areas

The better intelligence-gathering capability predicted will necessitate better modeling of the intelligence process. The present inability to model detection of units has been previously discussed.

Increase automation in C^3 systems should lead to greater accuracy of transmission of information. This in turn may require increased emphasis on the modeling of C^3 , particularly so that differences between new C^3 systems and existing ones can be determined.

Some of the logistic and mobility interactions have already been noted under "Operational Environment."

Part IV

PROCEDURES FOR A FIRE SUPPORT MIX STUDY

I INTRODUCTION

The purpose of this part is to present, in summary form, suggested procedures for the use of an analyst in the conduct and management of a fire support mix study. This information is presented in the following format.

First, in Section II, "Steps in a Fire Support Mix Evaluation Study," a discussion of the basic steps of any good systems analysis is presented, along with a listing of the methodological elements for a fire support study. Section III, "Relationship of Existing and Alternative Techniques to Elements of the Fire Support Mix Evaluation Methodology," provides a synopsis of available techniques for the fire support methodology by key element and supporting models. Section IV, "Strengths and Weaknesses of Existing Methodologies," summarizes the capabilities of existing methodologies. Section V, "How Existing Studies Answer Fire Support Questions," relates the questions addressed in existing studies to the techniques used to answer them. Section VI, "Criteria for Evaluating a Completed Study," provides a checklist for evaluating existing studies. Section VII, "Pitfalls in Fire Support Mix Studies," briefly discusses eight pitfalls that the fire support analyst must be especially careful to avoid.

As previously stated, Part IV synthesizes fire support study procedures and being intentionally direct and to the point, is presented with little backup material. If the reader desires more information or justification for the material in this section, it will be found chiefly in Part II.

II STEPS IN A FIRE SUPPORT MIX EVALUATION STUDY

A. The Systems Approach

The following steps are general in nature and, although stated in the context of fire support mix studies, should be taken in any good systems analysis:

- (1) Identify the problem and state it explicitly--Fire support is a vast subject. The specific problem to be investigated must be identified, defined, and delimited. The fire support system comprises many subsystems, and it is important to establish which of them are at issue in the study at hand. The determination of the true objective of the study is often a complex task. It entails defining objectives that are not unduly restrictive but at the same time are within some reasonable scope.
- (2) Identify feasible alternatives to satisfy the problem--What viable options exist to satisfy the objective of the study? In the case of fire support, options include choices of mixes among and within the supporting arms of artillery, armor, naval guns, and aircraft. In identifying feasible mixes from the supporting arms, care must be taken to consider the weapon as a complete system; that is, the entire weapon system should be considered, not merely the ordnance delivery portion.
- (3) Determine the type of resource costs involved--Each alternative will generally require resources--dollars and men. These must be clearly identified for each alternative.
- (4) Define measures of effectiveness--The proliferation of MOEs in use in existing studies attests to the difficulty of finding measures that are acceptable to a broad spectrum of analysts and decision-makers. There are basically four reasons for this, all of which must be considered in the definition of MOEs. One is that performance measures are often confused with MOEs. A second is that it is very difficult to develop measures for systems with dissimilar missions. A third is the difficulty of interpreting

scenario-dependent MOEs. Fourth, because MOEs often must permit comparison of existing, planned, and speculative systems, relative risks should be included in the MOEs (as well as in the cost estimates).

- (5) Synthesize methodology for relating effectiveness and costs of alternatives to the study objective--This usually requires establishing mathematical or logical relationships (models) among the objectives, the alternatives, and the environment. These models can range from very simple to extremely complex.
- (6) Select a criterion for selection--To determine a preferred alternative, a rule for selecting among alternatives must be stated. In cost/effectiveness studies, the selection is usually best based on most effectiveness for a given cost or on least cost for a given level of effectiveness.

B. Specific Elements of a Mix Methodology

Part I of this Guide develops in considerable detail a systems approach to the fire support mix problem. A brief summary of that approach is given below in terms of the elements comprising the fire support mix evaluation methodology. Consideration of all of these key elements and their relationship to the combat functional areas of intelligence, C³, logistics, and mobility is a necessary part of a mix study.

For methodological purposes the fire support system can be thought of as comprising five processes:

- (1) Fire mission generation
- (2) Fire mission allocation
- (3) Fire support system effectiveness determination
- (4) Fire support resource cost analysis
- (5) Fire support system mix selection.

Once a problem is understood and stated explicitly (the first step in a systems analysis), a methodology structured around these five processes will satisfy the principles of the systems approach described above.

The cornerstone of the methodology is a procedure for developing fire missions. Fire missions produce a demand for fire support resources based on the operational environment and the threat. These fire missions must then be allocated among the fire support resources, and the effectiveness of the fire support system must be determined. Essential inputs to the allocation and effectiveness processes are the weapon mixes to be considered, the performance characteristics of those weapon systems, and the characteristics of the weapon support system.

The cost analysis determines the resource costs entailed in achieving and maintaining the postulated level of effectiveness over some period of time.

The final process of fire support system mix selection relates effectiveness to cost and, on the basis of a specified criterion or criteria, selects a preferred fire support system for the consideration of the decision-maker.

III RELATIONSHIP OF EXISTING AND ALTERNATIVE TECHNIQUES TO ELEMENTS OF THE FIRE SUPPORT MIX EVALUATION METHODOLOGY

Various techniques have been used to address different elements of the fire support problem. In this section the techniques actually used in the researched studies, together with some feasible alternative techniques, are identified in matrix form for both the key elements of the fire support methodology and for important supporting models. It is of interest to note that the number of viable techniques and alternatives is less than might be expected. Techniques of interest can be pursued further by referring to Part II and Appendix C.

A. Matrix Relating Existing and Alternative Techniques to Key Elements of the Fire Support Problem

In Table 24 the existing techniques are related to the key elements of the fire support problem. The studies identified in parentheses after the existing techniques represent particularly good examples of how each of these techniques has been applied.

B. Matrix Relating Existing and Alternative Techniques to Supporting Models

In Table 25 the existing techniques are related to supporting models in the area of weapons effects and the functional areas of combat (other than firepower, which contains fire support). Once again the studies identified in parentheses represent good examples of how these techniques have been applied.

Table 24

MATRIX RELATING EXISTING AND ALTERNATIVE METHODOLOGIES TO KEY ELEMENTS OF FIRE SUPPORT PROBLEM

Methodology	Key Elements					
	The Overall Fire Support System	Mission Generation	Mission Allocation	Fire Support System Effectiveness	Cost Analysis	Mix Selection
Existing	Compartmentalized models (NWL)	War games (NWL)	Predetermined by experts by target type (NWL)	Simulation (DEMS)	Program costs	Subjective (WSEG)
	Single model (DYNTACS)	Historical data (Legal Mix)	Cost/weight (WSEG)	Analytical (DYNTACS)	Multiuse costs	Costs and effectiveness (Lockheed/USMC)
	Separate analysis (RAC)	Two-sided models (LEGION) Probabilistic mission sequence sampling (MAFAR)	Quickest kill (CNA)	Qualitative/quantitative (RAC)		Fixed cost or fixed effectiveness (CNA) Cost/effectiveness with optimization (NWL)
Alternatives	Hierarchy of models	Improved computer-aided war games	Operationally realistic criteria	More aggregation	Inclusion of risk	Inclusion of risk analysis
	Single dynamic model, e.g., DYFSS	Two-sided aggregate model, e.g., FSSAM	Automated optimization as an aid	Inclusion of uncertainty	More sensitivity analysis	

Table 25

MATRIX RELATING EXISTING AND ALTERNATIVE METHODOLOGIES TO FIRE SUPPORT SUPPORTING MODELS

Methodology	Supporting Models				
	Intelligence/ Target Acquisition	C ³	Weapon Effects	Logistics	Mobility
Existing	Individual sensor/target pair analysis (Legal Mix)	Model of command and control structure (CNA)	Analytic model of damage, including all first-order factors (NWL)	System by system logistics impact assessment (Lockheed/USMC)	Detailed in simulation (LEGION and Legal Mix)
	Part of war game (NWL)	Part of war games (NWL)	Round-by-round assessment (DYNTACS)	Considered only inputs of ammo supply and resupply rates (DEMS)	Part of war games (NWL)
	Aggregated values for whole classes of sensors and targets (Lockheed/USMC)	Use of delay times only (DEMS)	Firepower measures-- lethal areas estimated (Lockheed/USMC) Aggregate by target type (CNA)		Presimulation analysis for input (Lockheed/USMC)
Alternatives	Surveillance model (CRESS) Unit versus unit detection model Analytic model for developing aggregate measures	Include accuracy of messages	Include random element	Expand modeling of entire logistic system Adapt, integrate, and expand existing detailed logistic models	Making modeling more dynamic-sensitive to changing situation

IV STRENGTHS AND WEAKNESSES OF EXISTING METHODOLOGIES

Table 26 provides a synoptic listing of the results of the evaluation of the methodologies available from the reviewed studies. These results are presented in the form of the major strengths and weaknesses in the current methodological state of the art.

Table 26

STRENGTHS AND WEAKNESSES OF EXISTING METHODOLOGIES

Methodology Element	Strengths	Weaknesses
Overall approach	<p>Good mission allocation procedures</p> <p>Adequate and varied weapon effects models</p>	<p>Unrealistic mission lists</p> <p>Paucity of two-sided models</p> <p>Uncertainty often ignored</p> <p>Little sensitivity analysis</p> <p>Target acquisition often ignored</p> <p>C³ inadequately handled</p> <p>Logistics support handled simplistically, if at all</p> <p>Infrequent use of optimization techniques for mix selection</p> <p>Lack of standard MOEs</p>
Fire mission generation	<p>War games</p> <p>High degree of realism resulting from human judgment</p> <p>Great detail possible</p> <p>Two-sided</p> <p>Historical data</p> <p>A measure of realism based on the use of actual battle data</p> <p>Gives numbers and ranges of target types</p> <p>Ease of use</p>	<p>War games</p> <p>Many players and controllers needed</p> <p>Very time and money consuming</p> <p>Limited flexibility for excursions</p> <p>Gives single sample of a random process</p> <p>Historical data</p> <p>Less realism than war games</p> <p>One-sided in use</p> <p>Shortage of adequate data</p> <p>Possibility of biased data</p> <p>Difficult to adapt to new systems and concepts</p>
Mission allocation	Generally well modeled	Lack of a consistent set of criteria for allocation
System effectiveness	<p>Generally thoroughly modeled</p> <p>Good supply of weapon effects data</p>	<p>Weak supporting models for intelligence, C³, and logistics</p> <p>Little treatment of uncertainty</p>
Mix selection	<p>NWL's fixed effectiveness analytical model</p> <p>Lockheed/USMC's qualitative/quantitative approach</p>	<p>Proliferation of MOEs</p> <p>Few sensitivity analyses</p> <p>Risk ignored</p>
Cost analysis	<p>Program cost models</p> <p>Many well-developed cost techniques</p>	<p>Little wartime costing</p> <p>Little time-phased costing</p> <p>No treatment of uncertainty</p> <p>Difficulty of multimission costing</p>

V HOW EXISTING STUDIES ANSWER FIRE SUPPORT QUESTIONS

It is of value to know how other analysts have approached fire support problems. To facilitate this understanding, Table 27 summarizes the methodologies applied in each of the researched studies either to answer the major questions of the study or, in the case of those devoted primarily to model development, to meet its objectives. In addition to these descriptions, the supporting arms considered and the treatment of the key methodological elements are presented for each study.

Table 27

FIRE SUPPORT QUESTIONS AND APPLIED METHODOLOGIES

Agency/ Study	Fire Support Question Objective	Applied Methodology								
		Overall Approach	Supporting Arms Addressed			Key Element Models			Costs*	
			Air	Naval Gun	Arty	Mission Generation	System Effectiveness*	Mix Selection	Model	Data
NWL	What are the coordinated fire support requirements for the conduct of an amphibious assault? What is the requirement for various weapon types? What is the least cost mix of systems and weapons to meet fire support requirements effectively?	War games, weapon system performance characteristics, and a cost analysis were used as inputs to three mix evaluation models: mix generation, fire support simulation, and mix preference. Results were given in terms of preferred mixes.	X	X	X	War games	Simulation	Nonlinear programming	X	
Lockheed/ USMC	Development of an appropriate battle environment consistent with future MAF operational concepts. Development of an analytical model to evaluate weapon system designs and organizational mixes. Development of a computer model and handbook.	Two studies were conducted. In the first, fire support mix system characteristics, mission requirements, weapon selection priority, and coverage and damage criteria were input to the performance analysis. Outputs of this analysis were combined with cost and logistic factors to make mix comparisons. In the second, which was primarily a model development effort, the Delta battle concept was introduced.	X	X	X	Historical data	Simulation	No model		X
Lockheed/ DEMS	Development of a dynamic effectiveness model to evaluate missile weapon systems and mixes.	A campaign is described for a given physical and tactical environment. Tactical phase lines determine force positions at particular milestones in the campaign. Within each phase there is a set of independent Delta Battles comprising subintervals of approach, preparation, closure, assault, reorganization, and movement. Output is provided in a battle-by-battle and phase-by-phase basis.	X		X	Map exercise	Simulation	No model		

* System effectiveness includes mission allocation.

[†] A distinction is made between studies that used their own cost models for developing costs and those that only presented cost data.

Table 27 (Continued)

Agency/ Study	Fire Support Question/Objective	Applied Methodology								
		Overall Approach	Supporting Arms Addressed			Key Element Models			Costs†	
			Air	Naval Gun	Arty	Mission Generation	System Effectiveness*	Mix Selection	Model	Data
CNA	What approaches to providing naval gunfire support can best meet the CMC and CNO requirements in terms of level and type?	Two scenarios were written, and a number of special situations were derived. Target lists were drawn up, and the target structure was used as input data to a computer simulation model that played various fire support forces against the set of targets. Simulation results were compared to determine the relative cost and effectiveness of alternative approaches to increasing the fire support capabilities of the fleet.	X	X	X	?	Simulation	No model		X
SRI/MAFAR	What segments of combat air support required by Marine Corps force operations can be performed most cost-effectively by Marine Corps attack and fighter aircraft? What total numbers and types of attack and fighter aircraft are required in the Marine Corps?	Three different analytical approaches were selected and the results were compared to determine similarities and differences. The subsequent analysis established the combined techniques best suited to meeting the study objective. The effectiveness analysis approaches used were: an aircraft mix effectiveness simulation model, a linear programming model, and a game-theoretic model.	X			Historical data	Simulation Linear program Game-theoretic	No model		X
USACDC/ Legal Mix IV	What numbers and types of field artillery units should be assigned to type divisions and force artillery? What is the combat effectiveness justification for inclusion of each artillery weapon system in the overall mix?	A preliminary analysis provided performance data for the comparison of various weapon system/ammunition combinations. Two approaches were then followed. The first optimized the total mix for the division slice before assigning the weapon system to tactical missions of direct support, division general support, and force general support by a subjective analysis. The second optimized the artillery requirements by echelon. Subjective analyses of survivability and mobility were included in each approach. An optimum mix comparison was made	X		X	Historical data	Simulation	No model		X

Table 27 (Continued)

Agency / Study	Fire Support Question/Objective	Applied Methodology								
		Overall Approach	Supporting Arms Addressed			Key Element Models			Costs [†]	
			Air	Naval Gun	Arty	Mission Generation	System Effectiveness *	Mix Selection	Model	Data
USACDC/ Legal Mix IV (cont.)		based on the results of these approaches, followed by a nuclear analysis. Finally, an analytical and subjective preferred mix analysis was conducted from which preferred mixes were ascertained.								
RAC	What is the value of ground-based and airborne fire support in all phases of ground combat operations? What fire support performance improvements can be expected from technological advances and new concepts?	The methodology was divided into two phases. The first phase involved a logical consideration of the implications of threat, military operations, and tasks to be performed on the characteristics and values of fire support systems. A functional analysis indicated the contribution of fire support to mission performance. The second phase consisted of evaluation of specific fire support system concepts in critical military situations by considering the means available for applying fires, the issues under consideration, a comparative analysis, and a sensitivity analysis.	X		X	Historical data	?	No model		X
WSEG	How do programmed and planned weapon systems for fire support compare in terms of cost and effectiveness in a limited war situation?	The capability of various weapon systems was compared on the basis of a few measures of effectiveness and cost at a single moment of the battle. Comparisons were made by developing performance estimates of availability, surface survivability, reliability, penetrability, and target kill potential. Each weapon type was analyzed and then a preferred weapon system was selected for a given target type. The results of these analyses were combined to select among artillery, aircraft, and naval guns on the basis of target type.	X	X	X	Historical data	Analytical	No model		X

Table 27 (Continued)

Agency/ Study	Fire Support Question/Objcctive	Applied Methodology								
		Overall Approach	Supporting Arms Addressed			Key Elcment Models			Costs†	
			Air	Naval Gun	Arty	Mission Generation	System Effectiveness*	Mix Selection	Model	Data
Ohio State U./ DYNTACS	What are the operational conse- quences for armored weapon systems in various environments and tacti- cal situations of design, organiza- tional, and doctrinal decisions?	A series of models of armored weapon systems was developed. The Dcsign Models predict performancce characteristics of individual weap- ons generally in terms of mobility, detection, firepower, and protec- tion. The Operation Models simu- late various combat engagements. The principal operations model, DYNTACS, is a high resolution simulation of combat engagements ranging in size from a single weapon to a battalion. Another model, COMAN, was developed to study large units in sustained action. DYNTACS and COMAN are used in conjunction with one another to determine a preferred force structure.			X	Part of DYNTACS (historical data)	Simulation	No model		
STAG/ LEGION	Development of a model to test plans dealing with organizations, equipment, and tactics at the division level.	The model is an operational, division level, war-gaming model in the form of a two-sided, free play (player is forced to make tac- tical decisions), closed, man- computer simulation. The simulated unit is a company or its equivalent. Each cycle of decisions represents 15 minutes of battle action. The model simulates surveillance, mov- ing and firing decisions, assess- ment, administrative support, and air action functions.	X		X	Part of model	Simulation	No model		

Table 27 (Concluded)

Agency/ Study	Fire Support Question/Objective	Applied Methodology								
		Overall Approach	Supporting Arms Addressed			Key Element Models			Costs [†]	
			Air	Naval Gun	Arty	Mission Generation	System Effectiveness*	Mix Selection	Model	Data
U. of Michigan	Development of analytic structures to predict the results of an artificial history of combat.	The Lanchester approach to combat analysis was explored in depth. Attrition coefficients were defined to comprise three multiplicative components: the attrition rate, the allocation factor, and the intelligence factor. Methods were sought to calculate these factors and to find solutions to the resulting differential equations. The area of stochastic duels was also addressed.	X	X	X	Unspecified input	Analytical (Lanchester)	No model		
SRI/ BALFRAM	What are the optimum tactics and strategies of military operations? What is the effectiveness of military contingency plans? What is the optimum defense force weapon mix satisfying specified sufficiency criteria?	BALFRAM is a highly stylized, military bookkeeping, software device used to investigate the contribution of the component Services to the effectiveness of proposed general purpose force contingency postures. It is broad in scope and highly aggregated. Diverse weapon systems and organizations have been incorporated as inputs to allow specific systems trade-offs consistent with the scenario-dependent roles and missions of the force under consideration.	X	X	X	Part of BALFRAM	Analytical (Lanchester)	No model		

VI CRITERIA FOR EVALUATING A COMPLETED STUDY

In evaluating a fire support mix study, the first requirement is adequate documentation for review. The second requirement is some means to validate the data and model if a model was used.

A RAC Guide* suggests that the following points be checked early in the review of any cost/effectiveness study, and they are pertinent here:

- Statement of criteria to judge effectiveness
- Statement of criterion used to select preferred alternative
- Use of incremental costs
- Explanation of logic of models
- Presence or lack of analysis of sensitivity of the results to significant data and assumptions.

Other points to be checked in the review process are the:

- Validity of the problem addressed
- Identification and reasonableness of assumptions
- Completeness of alternatives
- Interrelation of effectiveness and cost
- Treatment of uncertainty
- Logical derivation of conclusions and recommendations and feasibility in light of considerations external to the study effort.

* I. Keymont et al., "Guide for Reviewers of Studies Containing Cost/Effectiveness Analysis," Research Analysis Corporation, McLean, Virginia (October 1965).

VII PITFALLS IN FIRE SUPPORT MIX STUDIES

There are certain pitfalls that can easily entrap the designer of a methodology for a study having the scope and complexity of a fire support mix study. These pitfalls are presented in a synoptic form below to serve as cautions to the fire support analyst.

- (1) Worst-case analysis--Requirement development based solely on worst-case analysis is generally inappropriate because, being based on unrealistic or at best on atypical assumptions, the results of such a procedure place unwarranted demands on scarce resources.
- (2) Single scenario--More than one scenario is usually a requisite for a mix study. Mix requirements change dramatically with changing threats and environments. Decisions based on a single-scenario analysis will be subject to criticism. The broader the spectrum of scenarios, the better.
- (3) Unsanctioned input data--The quest for good, consistent input data for the fire support system must be unending. The data for a specific study should be meticulously gathered and, most importantly, thoroughly discussed with the decision-makers who will act on the study results. The analyst should seek the sanction of the decision-maker for the input data before they are used. Unsanctioned, although perhaps potentially good input data can result in an ineffective study.
- (4) Inappropriate use of existing methodologies--the analyst must be careful to ensure the appropriateness of existing methodologies and models before applying them to his specific problem. It is unlikely that he will find an existing set of procedures that fits his problems well. It is better to have an underlying methodological framework on which detailed, selected, specialized procedures are placed than to try to use a canned methodology and force the techniques of one study on another.

- (5) Too much detail--The level of detail appropriate for a given analysis depends on the objectives of the study and the availability of input. When the objectives call for selection among a set of alternatives, only those areas in which the alternatives differ need to be analyzed in detail. The areas of similarity can be treated in more aggregate terms. Also, analysts sometimes develop models without due regard to the availability of input. Detailed modeling of operations and systems for which little detailed data are available is only fruitful when parametric or sensitivity analyses can meet the study objectives.
- (6) Unrealistic input requirements--When confronted with a difficult modeling problem, there is a tendency for the analyst to relegate the problem to input. Such an approach often results in input requirements that are unrealistic. The analyst may do this feeling that the input is someone else's responsibility. However, such an approach is unrealistic and can produce a completely ineffective study.
- (7) Measures of performance versus measures of effectiveness--There are many cases of studies that confuse MOEs and performance measures. MOEs gauge how well a system meets its mission or goals in a specific threat and geophysical environment; performance measures refer to a system's ability to perform its design functions and are usually developed in a more or less environment-independent manner. Selection from system alternatives solely because of performance measures is usually inappropriate because such measures lack an operational basis. For instance, selection of a gun system based only on such performance measures as range and kill potential does not guarantee the best gun for realistic operational situations. MOEs, such as the number of targets killed, are more appropriate.
- (8) Concealed assumptions--A surprising number of studies fail to state explicitly the assumptions underlying their methodologies. This makes it difficult, if not impossible, to assess the results of the studies. The credibility of studies that fail to list their assumptions is often suspect, even though the assumptions may actually be completely acceptable.

GLOSSARY

A/C	Aircraft
ACV	Air cushion vehicle
AFS	Artillery fire support
AOA	Amphibious objective area
BALFRAM	Balanced Force Requirements Analysis Model
CAS	Close air support
CNA	Center for Naval Analyses
COMAN	Combat Analysis Model
CRESS	Combined Reconnaissance, Surveillance, and SIGINT
CTOL	Conventional takeoff and landing
C ³	Command, Control, and Communications
DE	Destroyer escort
DEMS	Dynamic Effectiveness Model Study
DYFSS	Dynamic Fire Support System Model (DYFSS)
DYNTACS	Dynamic Tactical Simulator
ECM	Electronic countermeasures
FEBA	Forward edge of battle area
FO	Forward observer
FSCC	Fire Support Coordination Center

FSCL	Fire support coordination line
FSSAM	Fire Support System Aggregated Model
H&I	Harrassing and interdiction
MAFAR	Marine Corps Attack and Fighter Requirements
MAG	Marine Air Group
MARSAS	Marine Search and Attack System
MIFASS	Marine Integrated Fire and Air Support System
MTACCS	Marine Tactical Command Communication and Control System
MOE	Measure of effectiveness
NFL	No-fire line
NGF	Naval gunfire
NGFS	Naval gunfire support
NWL	Naval Weapons Laboratory, Dahlgren, Virginia
OAFS	Offensive air fire support
POL	Petroleum, oil, lubricants
RAC	Research Analysis Corporation
RL	Rocket launcher
SPA	Supporting arms
SRI	Stanford Research Institute
STAG	U.S. Army Strategy and Tactics Analysis Group
TACT	Target acquisition and control team
TAOR	Tactical area of responsibility
TSOR	Tactical space of responsibility

USACDC U.S. Army Combat Developments Command

V/STOL Vertical/Short Takeoff and Landing

WSEG Weapon Systems Evaluation Group

Appendix A

LISTING OF FIRE SUPPORT SYSTEM PARAMETERS

Appendix A

LISTING OF FIRE SUPPORT SYSTEM PARAMETERS

The following figures result from an examination of the inputs and methodological functions of Figure A-1. Within the figures they are dissected into subelements and input factors or parameters that should be considered in a fire support mix evaluation.

The listings are comprehensive but not necessarily exhaustive. They are predicated on a knowledge of Marine Corps operations present and future and the fire support studies investigated in this study and described in Appendix C.

The order of presentation is as follows:

Figure A-2	Operational Environment Input Factors
Figure A-3	Threat Input Factors
Figure A-4	Fire Mission Generation Parameters
Figure A-5	Weapon Mix Generation Parameters
Figure A-6	Weapon System Performance Factors
Figure A-7	Weapon Support System Performance Factors
Figure A-8	Fire Mission Allocation Parameters and Factors
Figure A-9	Analysis Measures for Fire Support System Effectiveness
Figure A-10	Cost Analysis Parameters
Figure A-11	Preference Selection Criteria for Fire Support System Mix

The factors and parameters describe entities to which a value or values can be assigned for evaluative purposes. Each has an effect on

the ultimate preference for a fire support mix. It is not implied that each factor is applicable to all fire support system studies, but, depending on the objectives of a given study, each could become a key factor in the comparative evaluation of alternatives.

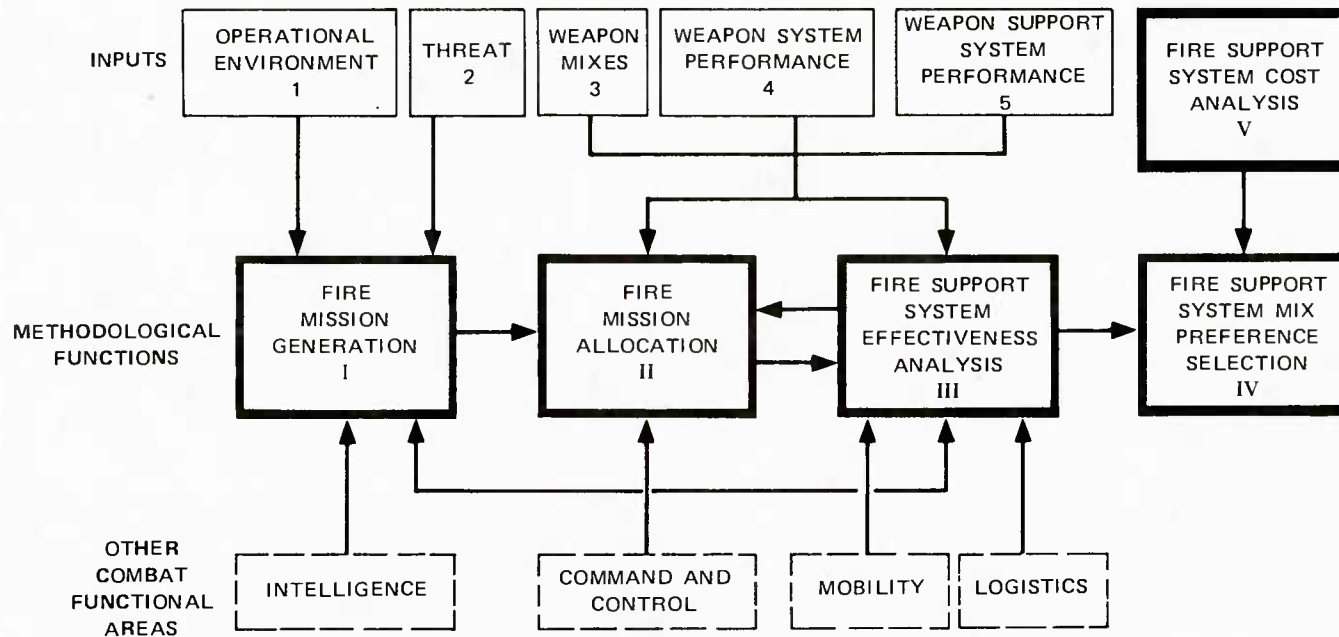


FIGURE A-1 INTERRELATIONSHIPS OF KEY ELEMENTS OF FIRE SUPPORT METHODOLOGY

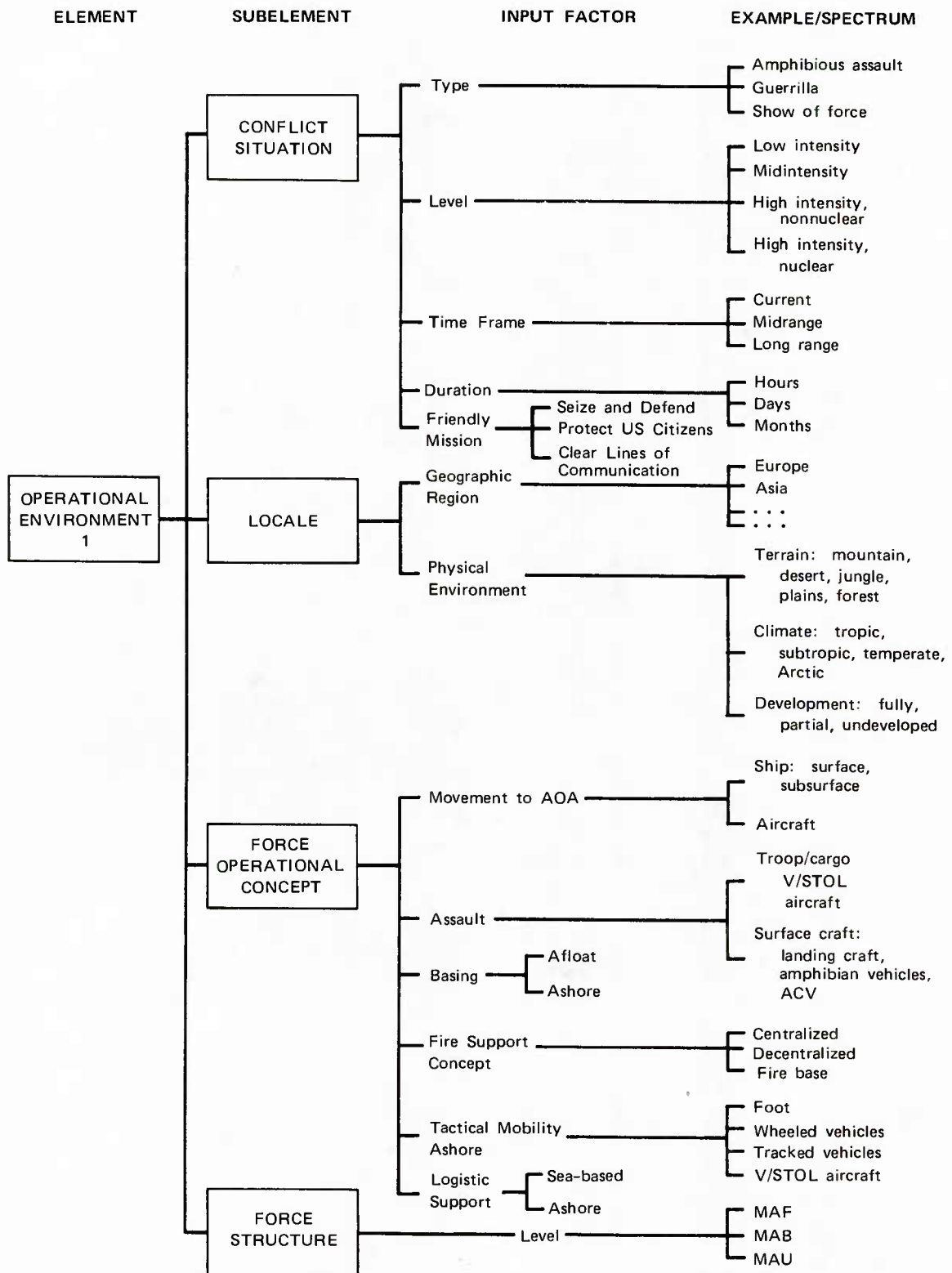


FIGURE A-2 OPERATIONAL ENVIRONMENT INPUT FACTORS

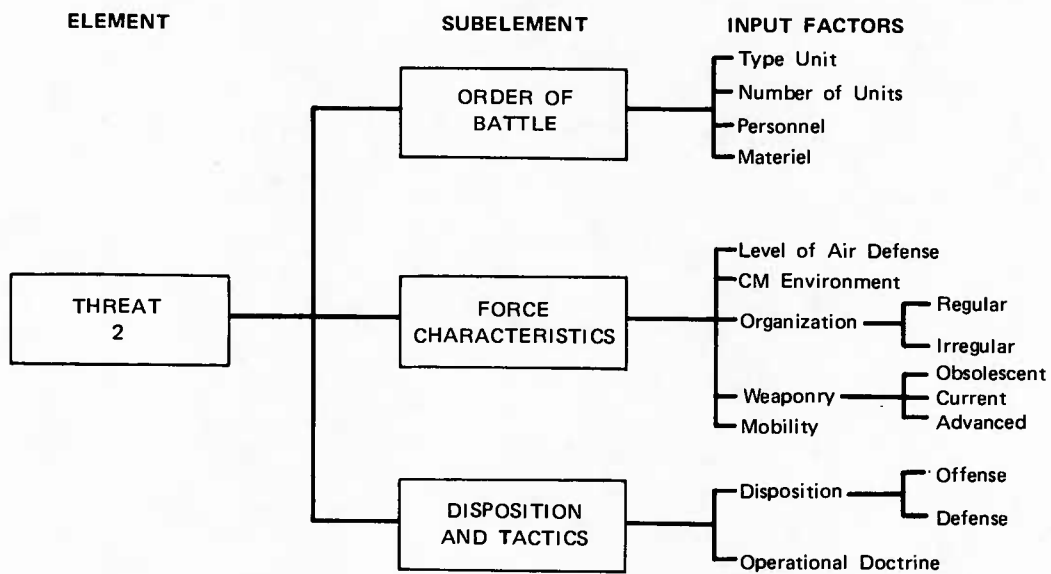


FIGURE A-3 THREAT INPUT FACTORS

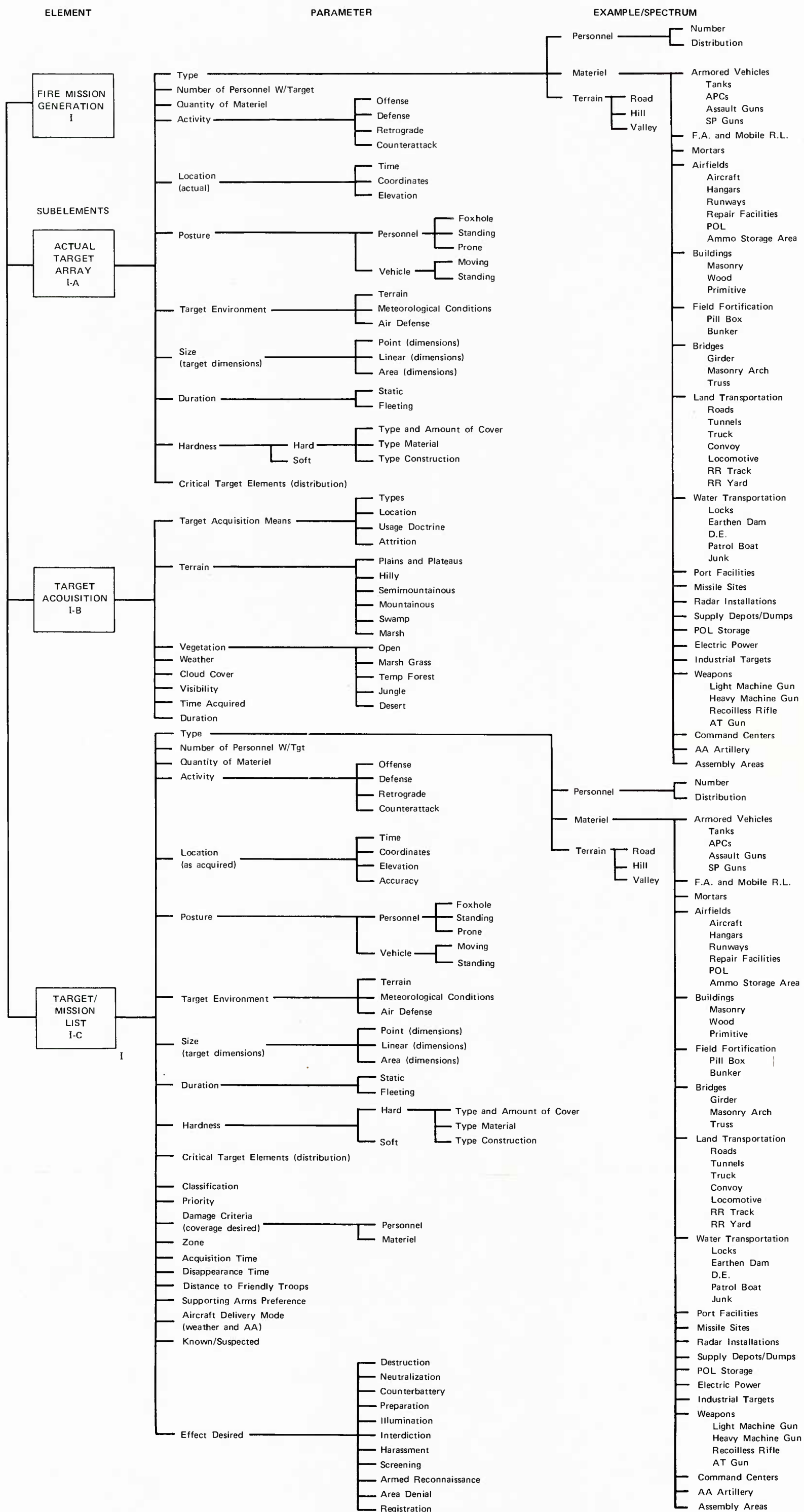


FIGURE A-4 FIRE MISSION GENERATION PARAMETERS

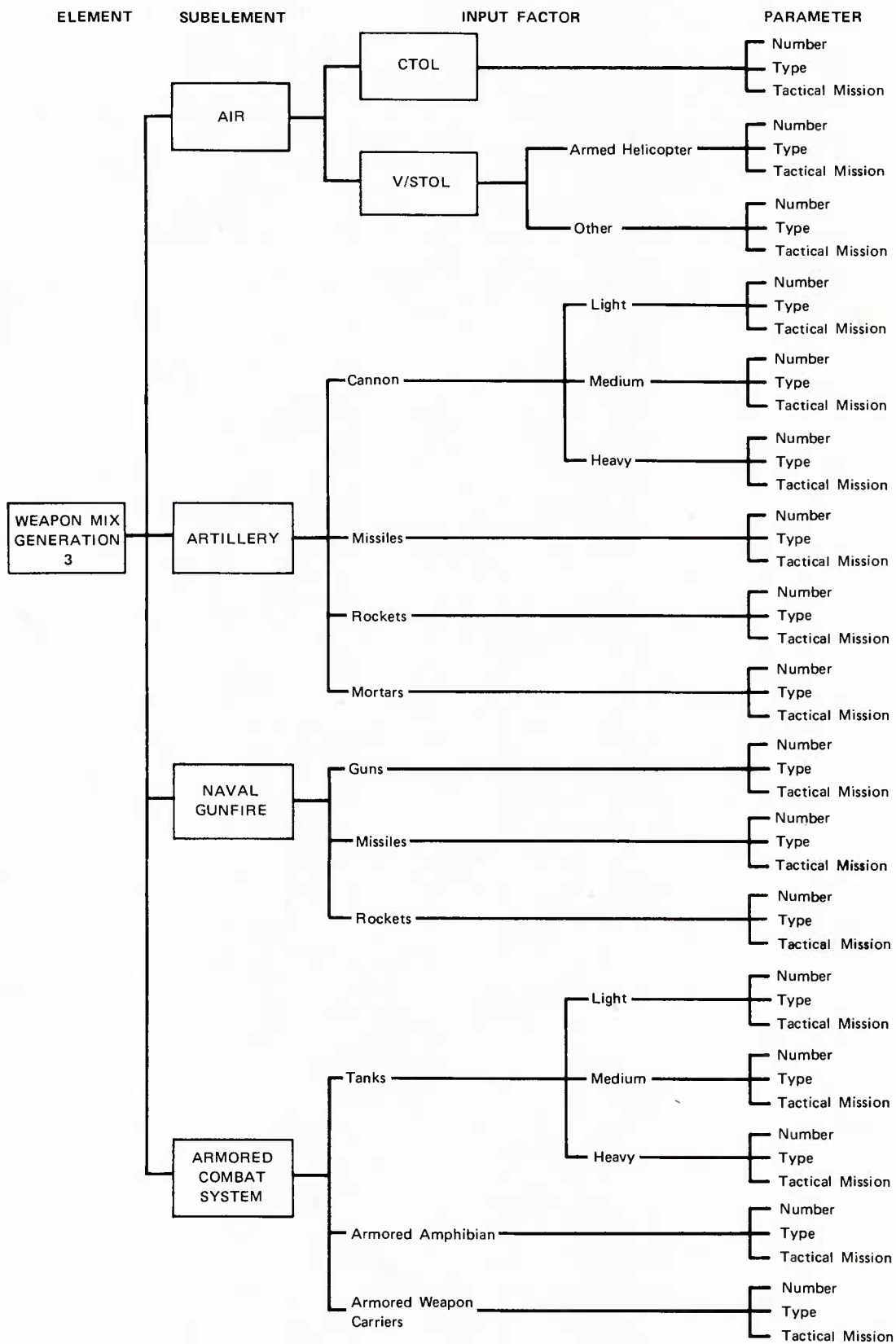


FIGURE A-5 WEAPON MIX GENERATION PARAMETERS

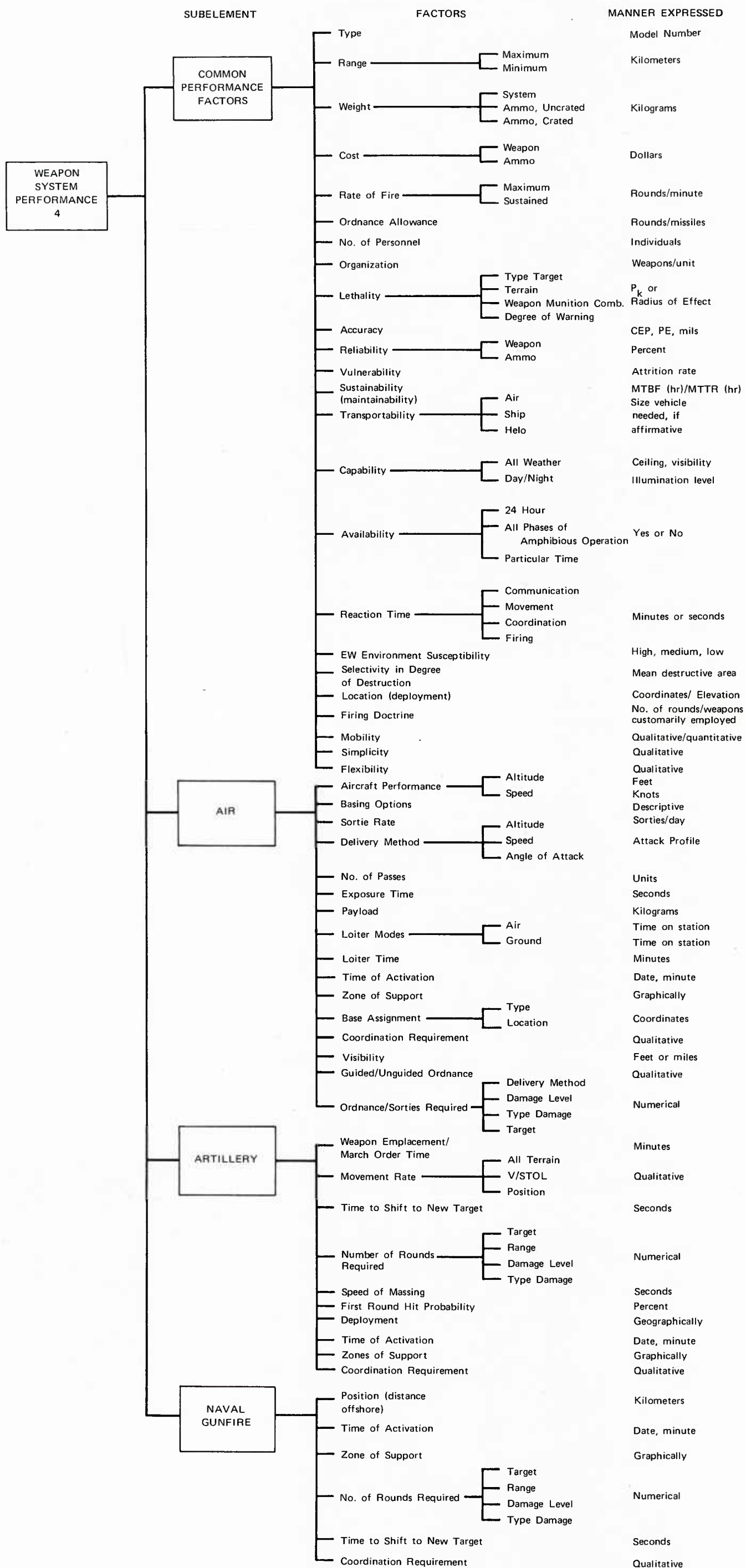


FIGURE A-6 WEAPON SYSTEM PERFORMANCE FACTORS

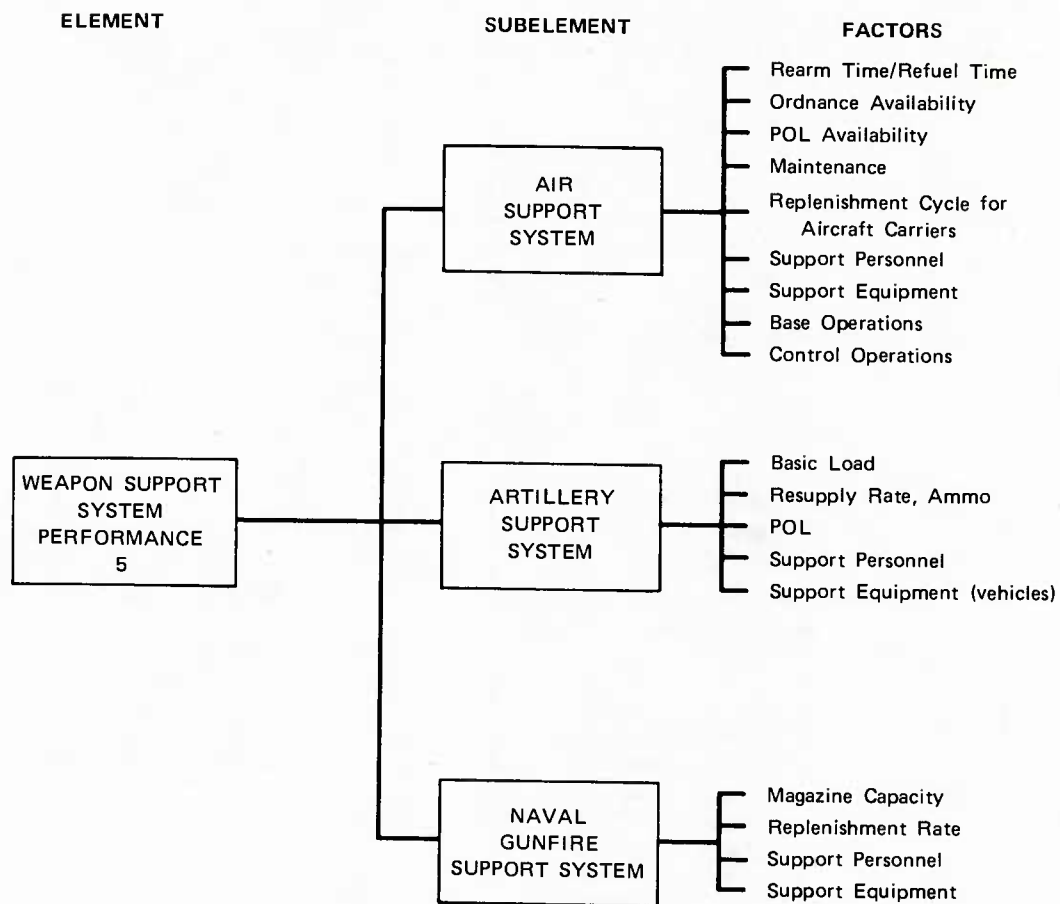


FIGURE A-7 WEAPON SUPPORT SYSTEM PERFORMANCE FACTORS

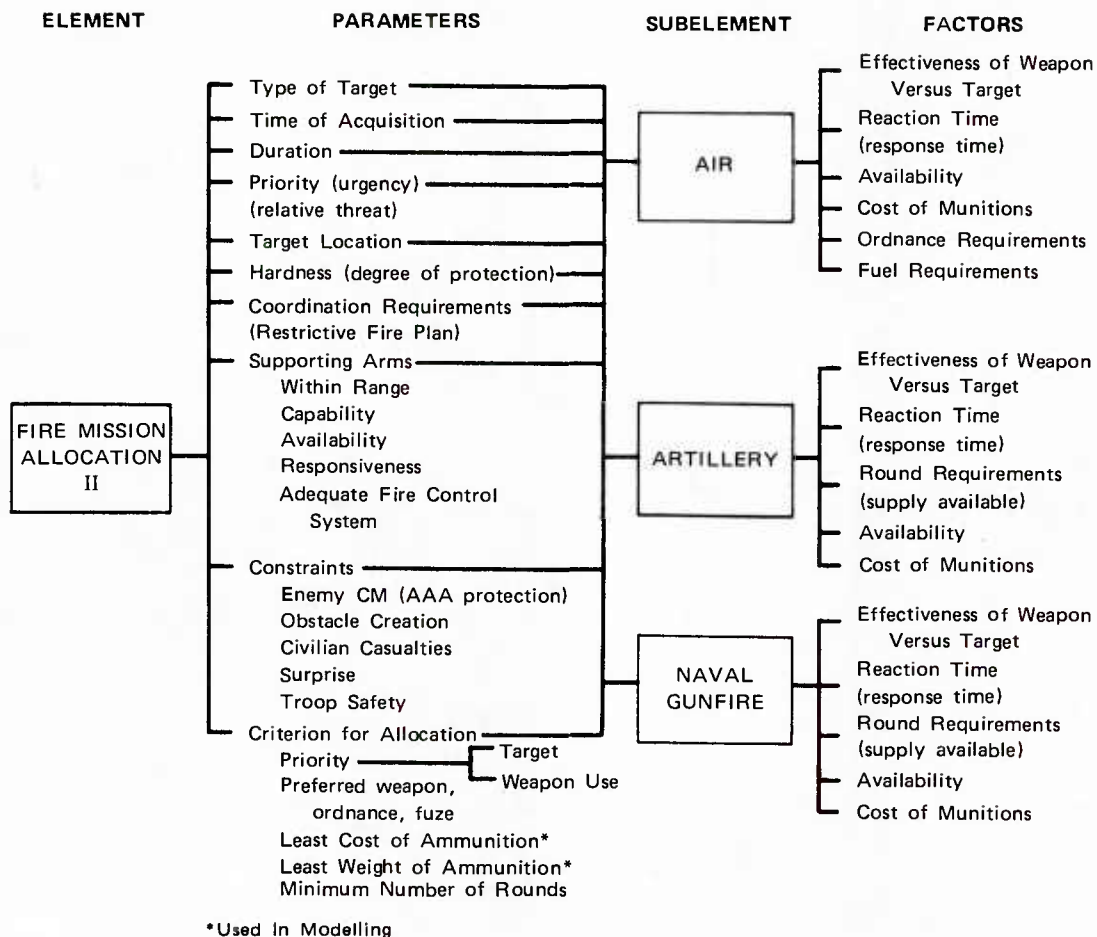
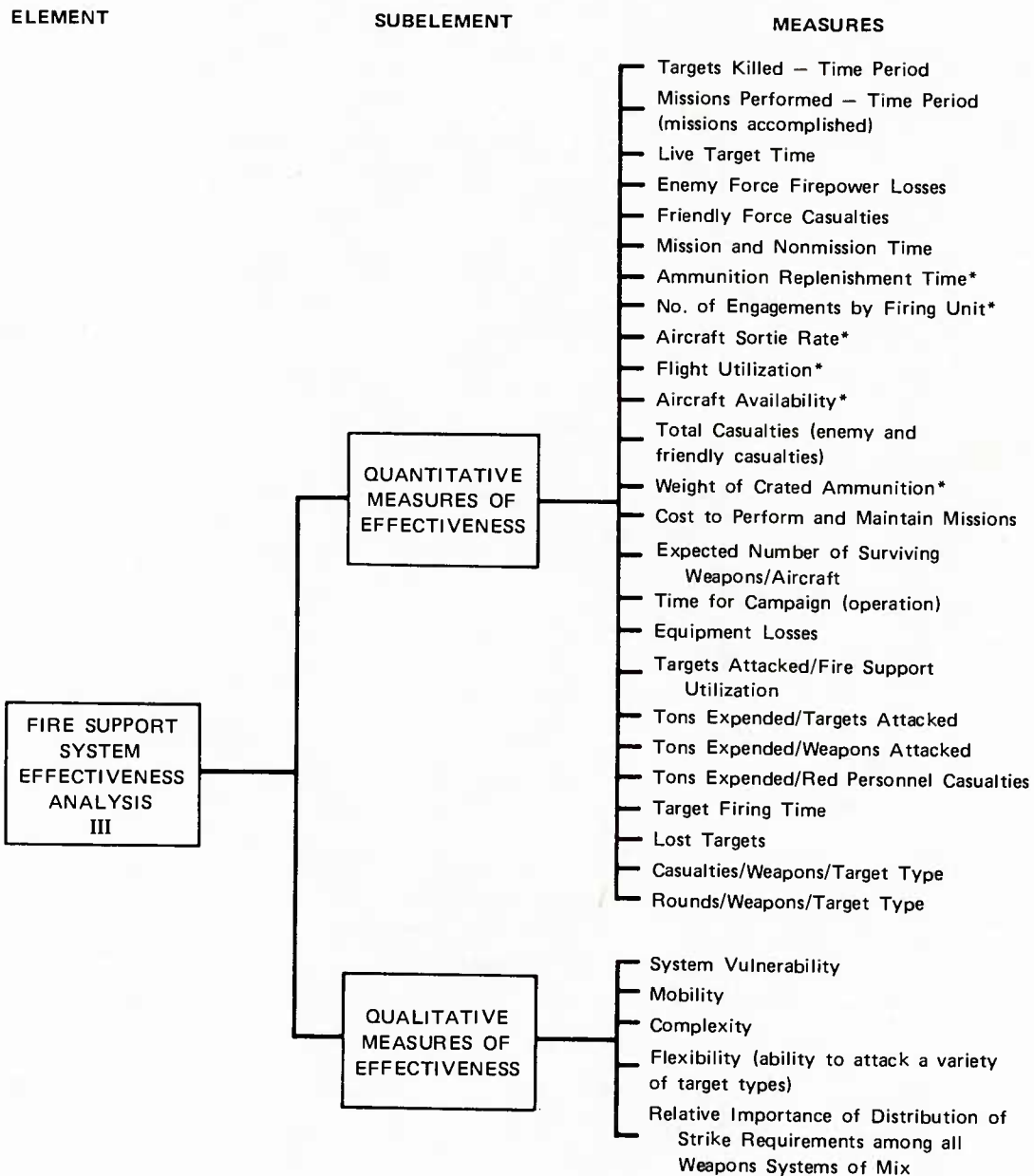


FIGURE A-8 FIRE MISSION ALLOCATION PARAMETERS AND FACTORS



*Measures of Performance

FIGURE A-9 ANALYSIS MEASURES FOR FIRE SUPPORT SYSTEM EFFECTIVENESS

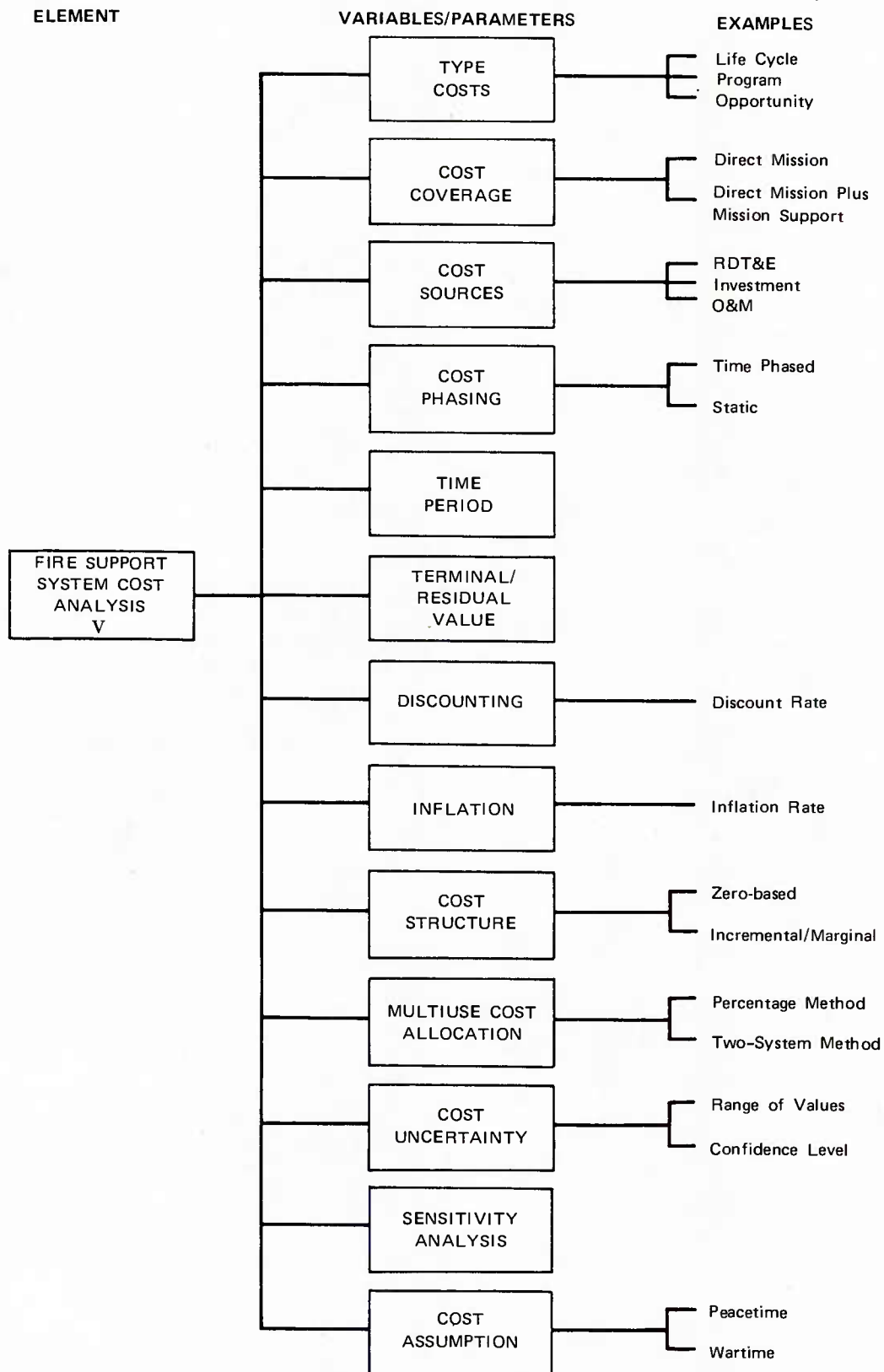
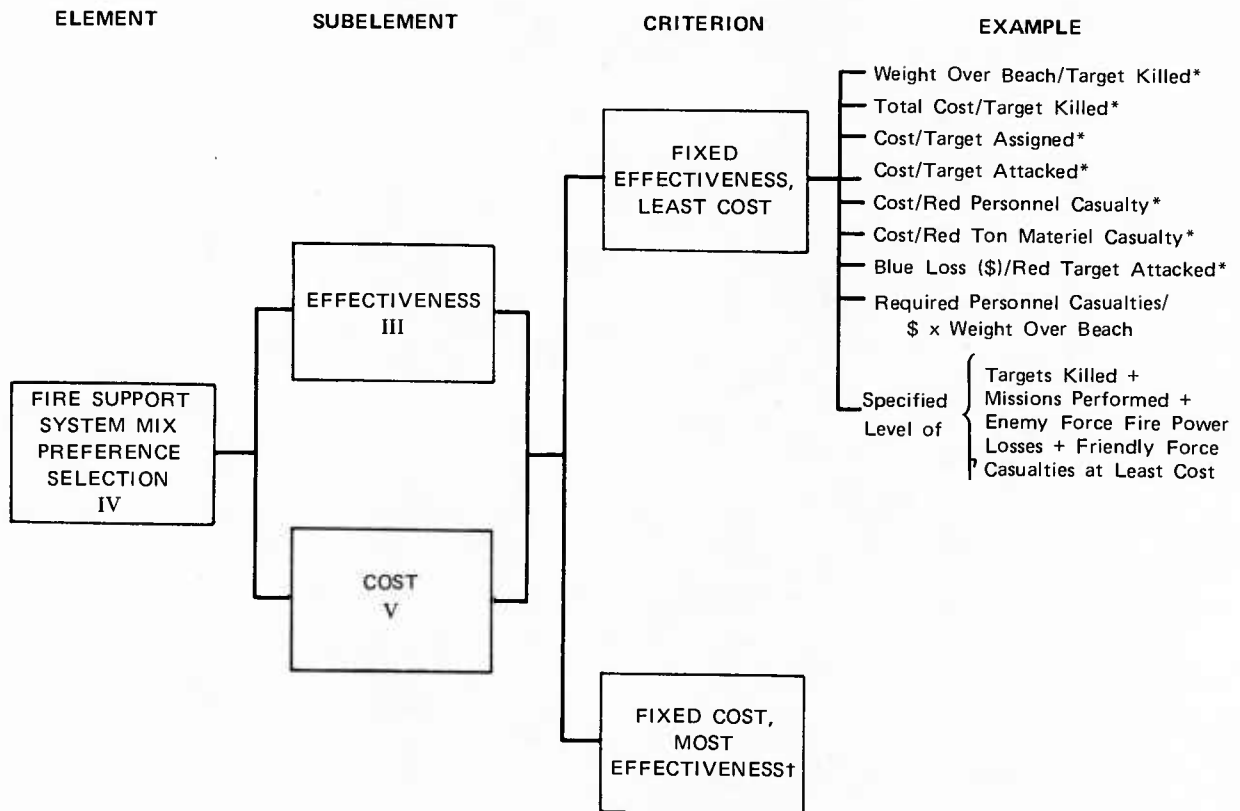


FIGURE A-10 COST ANALYSIS PARAMETERS



*These are really ratios of effectiveness to cost and are not suitable criteria of choice unless an absolute level of effectiveness or cost is fixed.

†Examples are similar to those examples given for fixed effectiveness, least cost.

FIGURE A-11 PREFERENCE SELECTION CRITERIA FOR FIRE SUPPORT SYSTEM MIX

Appendix B

BIBLIOGRAPHY

BIBLIOGRAPHY

- "Ammunition Expenditure Rate (U)," a report bibliography, Search Control No. 076181, Defense Documentation Center, Defense Supply Agency, Cameron Station, Alexandria, Virginia (4 January 1972), SECRET.
- "Assessment of Combat Effectiveness (U)," Final Report 1965-1990, LAS LOG No. 65-128, U.S. Army Combat Developments Command, Institute of Advanced Studies, Carlisle Barracks, Pennsylvania (December 1965), CONFIDENTIAL. AD 392 933L
- Bruce, C. A., Jr., et al., "CARMONETTE III Documentation," Vol. II: "Data Preparation Guide," Report RAC-R-28, Research Analysis Corporation, McLean, Virginia (February 1968). AD 827 900L
- "Catalog of Computerized Models," USACDC Pam 71-11, U.S. Army Combat Developments Command, Fort Belvoir, Virginia (1 July 1969). AD 857 275
- "Catalog of War Gaming Models" (5th Edition), SAGA-209-71, Studies, Analysis and Gaming Agency, Organization of the Joint Chiefs of Staff, The Pentagon, Washington, D.C. (30 June 1971), FOR OFFICIAL USE ONLY. AD 887 668L
- Clark, G. M., et al., "Land Combat Model DYNCOM--Missile and Electronic Countermeasures Models (U)," Final Report, RF 2376 FR-5, Systems Research Group, Department of Industrial Engineering, Ohio State University, Columbus, Ohio (January 1971) SECRET. AD 517 621
- Clark, G. M., and S. H. Parry, (eds.), "Small Unit Combat Simulation (Dyntacs X) Counterbattery Fire Models," Final Report RF 2978--FR 70-1, Systems Research Group, Columbus, Ohio (October 1970). AD 882 877L
- Eckhardt, W., and D. W. Mader, "CARMONETTE III Documentation," Vol. I: "General Description," Report RAC-R-28, Research Analysis Corporation, McLean, Virginia (October 1967). AD 822 400L
- Eckler, A. Ross, and Stefan A. Burr, "Mathematical Models of Target Coverage and Missile Allocation," Military Operations Research Society, Alexandria, Virginia (1972).

Edwards, M. O., et al., "Guns and Howitzers (Towed and Self-Propelled)-- Free World (U)," Final Report, Project 6483, Stanford Research Institute, Menlo Park, California (12 June 1968), SECRET/NOFORN. Prepared for U.S.A. Weapons Command, Rock Island Arsenal under Contract DAAF03-67-C-0064-P001.

"EINFALL: A New Land Battle Simulation (Revised)," SSC-TN 5205-86, Stanford Research Institute, Menlo Park, California (October 1969).

"General Operational Requirement, SPA-1, Supporting Arms (U)," Department of the Navy, Headquarters U.S. Marine Corps, Washington, D.C. (April 1972), SECRET/NOFORN.

Gigliotti, R. R., "The National Tactical Air Requirements Analysis Study (U)," short title: "NATAX," Volume 1: "Summary, Findings, Discussion," Study No. 58, Naval Warfare Analysis Group, Center for Naval Analyses, an affiliate of the University of Rochester, Rochester, New York (November 1968), SECRET.

Hornung, J. P., H. S. Sundt, and A. G. Schorr, "Automated Fire Support Artillery (AFSA) Model," Vol. I: "Model Description," Final Report CORG-M-339, Technical Operations, Inc., Combat Operations Research Group, Alexandria, Virginia (May 1968). AD 841 361

"Legal Mix III--Optimum Mix of Artillery Units 1971-1975 (U)," Phase III, U.S. Army Combat Developments Command, Field Artillery Agency, Fort Sill, Oklahoma (August 1968).

Vol. I: "Main Report," SECRET-RD. AD 507 064L

Vol. II: Annex F: "Methodology," and Annex G: "Basic Data General Discussion," SECRET-RD. AD 507 065L

Vol. III: Annex H: "Europe," SECRET-RD, NOFORN. AD 507 066L

Vol. IV: Annex I: "Korea," SECRET-RD. AD 507 067L

Vol. V: Annex J: "Southeast Asia," SECRET/NOFORN. AD 507 068L

Leinweber, C. L., "Aerial Artillery System Concepts (U)," Final Report D2-121654-1, The Boeing Company, Seattle, Washington (December 1969), SECRET.

Loomis, H. W., "Nonlinear Methods Used in the Fire Support Study," Technical Report TR-2862, U.S. Naval Weapon Laboratory, Dahlgren, Virginia (April 1973).

"Marine Corps Long-Range Plan (MLRP) (U)," Department of the Navy,
Headquarters U.S. Marine Corps, Washington, D.C. (December 1971),
SECRET/NOFORN.

Mitchell, N. E., et al., "Final Report on Impact of Semi-Active Laser
Guidance (U), Vols. I and II," RAC-R-139, Research Analysis Corpora-
tion, McLean, Virginia (April 1972), CONFIDENTIAL.

_____, "Technological Alternatives and Mixes for 1975-85 Army Fire
Support Systems (U)," RAC-R-120, Vol. IV: Appendix, "Description
of Alternative Support Weapon Systems (U)," Research Analysis Corpo-
ration, McLean, Virginia (May 1971), SECRET. AD 515 384L

Mitchell, N. E., F. M. Newman, and J. A. Orr, "Technological Alternatives
and Mixes for 1975-85 Army Fire Support Systems (U)," Volume 1:
"Executive Summary," Rac-R-120, Research Analysis Corporation, McLean,
Virginia (April 1971), SECRET. AD 515 383L

"Naval Fire Support (U)," a report bibliography, Search Control No. 076234,
Defense Documentation Center, Defense Supply Agency, Cameron Station,
Alexandria, Virginia (4 January 1972), SECRET.

"Navy Strategic Study FY 1975-1989 (NSS 75-89) (U)," Department of the
Navy, Chief of Naval Operations, Washington, D.C. (5 February 1969),
SECRET/NOFORN.

"Nonnuclear Employment of Field Artillery Weapon System (U)," FM6-141-1,
Headquarters, Department of the Army, Washington, D.C. (January 1967),
CONFIDENTIAL.

Odom, C. T., J. W. Kramar, and A. S. Thomas, "An Improved Model for Eval-
uating Artillery Weapons," Report No. 1321, U.S. Army Ballistic Re-
search Laboratories, Aberdeen Proving Ground, Maryland (September
1966). AD 807 403

"Operational Concepts for Employment of Amphibious Task Forces in the
Mid-Range Period (FY 73-80) (U)," Final Report, Department of the
Navy, Office of the Chief of Naval Operations, Washington, D.C.
(21 March 1972), SECRET/NOFORN.

Perkins, R. A., Jr., "Requirements for Field Artillery Models of Combat,"
Master's thesis, Naval Postgraduate School, Monterey, California
(April 1970). AD 708 047

Program A, CORG, "Tank Antitank Assault Weapons Requirements Study (TATAWS) Division War Game Analysis (U)," Volume I: "Basic Report," CORG-M-367, Combat Operations Research Group, Technical Operations, Inc., (May 1969), CONFIDENTIAL. AD 504 268

"Requirements Study on Fire Support Systems," (CMC Project No.- Unnumbered), Marine Corps Landing Force Development Center, Quantico, Virginia (1963), SECRET-RD.

"A Review of Some Ground-Combat Simulation Models," Technical Memorandum No. 45, Army Materiel Systems Analysis Agency, Aberdeen Proving Ground, Maryland (August 1969). AD 589 590

Schaffer, M. B., "Basic Measures for Comparing the Effectiveness of Conventional Weapons," RM-4647-PR, The Rand Corporation, Santa Monica, California (January 1966).

Schleuter, G., and Olson, S., "Operational Simulation of a Cannon-Launched Guided Projectile System (U)," Technical Report No. RE-TR-71-23, Research and Engineering Directorate, U.S. Army Weapons Command (AMSWE-RE), Rock Island, Illinois (April 1971), CONFIDENTIAL. AD 515 031

"U.S. Navy Long Range Objectives (LRD-81) (U)," Department of the Navy, Chief of Naval Operations, Washington, D.C. (August 1969), SECRET/NOFORN.

"The USMC in 1990: A Long Range Study (U)," Department of the Navy, HQMC, Washington, D.C. (November 1971), SECRET.

"USMC Mid-Range Objectives Plans FY 1973-1982 (U)," Department of the Navy, HQMC, Washington, D.C. (November 1971), SECRET.

DISTRIBUTION LIST

ORGANIZATION	NO. OF COPIES	ORGANIZATION	NO. OF COPIES
Assistant Secretary of Defense Systems Analysis Department of Defense Washington, D.C. 20301	1	Naval Air Systems Command Department of the Navy Washington, D.C. 20360	2
Director Weapons Systems Evaluation Group Department of Defense Washington, D.C. 20301	1	Naval Ordnance Systems Command Department of the Navy Washington, D.C. 20360	2
Joint Chiefs of Staff Studies, Analysis and Gaming Agency Washington, D.C. 20210	1	Naval Ships Systems Command Department of the Navy Washington, D.C. 20362	2
Defense Documentation Center Cameron Station Alexandria, VA 22314	1	Naval Ship Research and Development Center Bethesda, MD 20034	1
Chief of Naval Operations Department of the Navy Washington, D.C. 20350		Naval Weapons Laboratory Dahlgren, VA 22448	2
(Op-090)	1	U.S. Army Material Command 5001 Eisenhower Avenue Alexandria, VA 22304	
(Op-96)	1	(Code AMCDL)	1
(Op-03)	1	(Code AMCMA)	1
(Op-04)	1	(Code AMCMS)	1
(Op-05)	1	(Code AMCPA-SA)	1
(Op-06)	1	(Code AMCRD-W)	1
Chief of Naval Research Department of the Navy Arlington, VA 22217		U.S. Army Field Artillery School Combat & Training Development Directorate Ft. Sill, OK 73503	1
(Code 462)	2		
(Code 463)	1	Combined Arms Center Development Activity War Games Division Ft. Leavenworth, KA	
Chief of Naval Material Department of the Navy Washington, D.C. 20360	2	(Attn: Roger Willis)	1
Director Chief of Naval Material Development Washington, D.C. 20360		MUCOM Operations Research Group Aberdeen Proving Ground, MD 21010	
(MAT-03M)	1	(Attn: AMSMU-OR)	1
Commander Amphibious Force U.S. Pacific Fleet San Diego, CA 92155	1	U.S. Army Electronics Command Fort Monmouth, NJ 07703	
Commander Amphibious Force U.S. Atlantic Fleet Norfolk, VA 23520	1	(Attn: AMSEL-PL)	1
Commander Amphibious Training U.S. Atlantic Norfolk, VA 23520	1	U.S. Army Material Systems Analysis Agency Aberdeen Proving Ground, MD 21005	
Commanding Officer Naval Amphibious School, Coronado San Diego, CA 92155	1	(Attn: AMXSY-T)	2
		U.S. Army Aviation Systems Command P. O. Box 209 St. Louis, MO 63166	
		(Attn: AMSAV-R-X (Mr. Hollis))	1
		U.S. Army Missile Command Redstone Arsenal, AL 35809	
		(Attn: AMSMI-DA)	1

ORGANIZATION	NO. OF COPIES	ORGANIZATION	NO. OF COPIES
U.S. Army Munitions Command Dover, NJ 07801 (Attn: AMSMU-RE-R)	1	Advanced Research Projects Agency 1400 Wilson Blvd. Arlington, VA 22209	1
U.S. Army Weapons Command Rock Island, IL 61202 (Attn: Sys Anal Ofc)	1	Center for Naval Analyses 1401 Wilson Blvd. Arlington, VA 22209	1
Commandant of the Marine Corps Headquarters, U.S. Marine Corps Washington, D.C. 20380 (Code AX)	10	U.S. Naval Postgraduate School Monterey, CA 93940	1
Commanding General Fleet Marine Force, Atlantic Norfolk, VA 23511	1		
Commanding General Fleet Marine Force, Pacific FPO San Francisco, CA 96610	1		
Commanding General Marine Corps Development and Education Command Quantico, VA 22134 (Education Center)	1		
(Development Center)	10		
Officer in Charge MTACCS Test Bed Division Marine Corps Base Camp Pendleton, CA 93055	1		
Commander Frankford Arsenal Philadelphia, PA 19137	1		
Chief, Analytical Sciences Office USA Biological Defense Research Laboratory Dugway, UT 84002 (Attn: AMXBL-AS)	1		
Harry Diamond Laboratories Washington, D.C. 20438 (Sys Anal Ofc)	1		
Commander U.S. Army Training and Doctrine Command Fort Monroe, VA 23651 (Attn: DC/S for Operations and Intelligence (ATOI-IC-SMI)	1		
U.S. Army Combat Developments Command Armor Agency Fort Knox, KY 40121	1		
U.S. Army Strategy and Tactics Analysis Group (STAG) 8120 Woodmont Avenue Bethesda, MD 20014	1		
Directorate, Weapon Systems Analysis (DACS-CWC) Office of Vice Chief of Staff United States Army Washington, D.C. 20360	1		

DUDLEY KNOX LIBRARY - RESEARCH REPORTS



5 6853 01001574 6

U155067